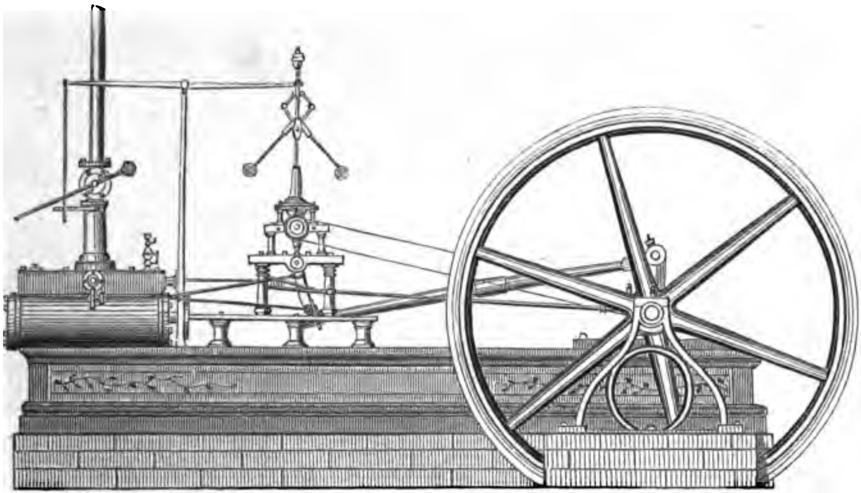

Horizontal Steam-engine used to propel the Machinery in the Publishing House of the M. E. Church, South.

THE

STEAM ENGINE.

EDITED BY

THOMAS O. SUMMERS.

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Contents.

Preface.

THIS is a most satisfactory book on the Steam-Engine—a subject interesting to every one. In these days, when there is so much travelling by land and by water, in the steamboat and the rail-road car, no one should be ignorant of that powerful agent by which we have almost succeeded in annihilating both time and space. In view of this, we have carefully revised the present work, which is admirably adapted to the Family, or Young People's Library, and may be profitably put into the pocket to be read when in a boat or car.

The Editor.

NASHVILLE, TENN., June 7, 1855.

THE

STEAM-ENGINE.

INTRODUCTION.

For the last two hundred years there has been a large class of industrious and intelligent men who have employed themselves in scientific investigations. By them the earth has been explored: they have ascended to the summits of its mountains, and descended into the depths of its cavities. They have measured and weighed the globe itself, and from its strata drawn the materials for the exercise of their ingenuity and skill. With shrewd and patient observation they have combined and separated different substances, searching out their various elements, properties, and affinities. Nothing, in short, has escaped their curiosity and research. The very sunbeam has been stopped by them in its way, and directed through prisms, that they might ascertain its character and composition; which, when discovered, they have applied to copy the forms and colors of the things which the bright beam illuminates. But of all they have done, nothing is more strange, nor more important to the human race, than their investigation of steam, which, by

an ingenious mechanical contrivance, they have, in THE STEAM-ENGINE, employed as a motive force.

The purposes to which this wonderful triumph of human ingenuity has been applied are numerous and diversified. From depths, inaccessible without its aid, it draws the metal from which other engines may be constructed, and the coal destined to give them activity. By its assistance iron is rolled, drawn, forged, and formed into shapes for machines which it puts into motion, spinning and weaving every article of dress, from the delicate fancy lace to the closely woven woollen cloth. It lifts, draws, bores, drills, planes, saws, and, with an exactitude not to be obtained by any manual skill, may be applied to almost every mechanical process. By its power we are conveyed on land at a speed which, thirty years ago, would have been deemed fabulous; or transported, with ease and comfort, over river, lake, and sea, in defiance of current, wind, or tide. The question seems no longer to be, "What can steam do?" The inquiry rather is, "What remains for it to accomplish?"

This mighty engine is the application of a well-known and easily understood natural force, but one from which it could scarcely have been imagined that such important results were to be obtained. The vapor which flows in white streams from the spout of a tea-kettle when water is boiling, is the moving power of that mechanism by which such varied labors are performed. To describe the gradual steps by which

the properties of this vapor and their applicability to the wants of social life were discovered, will form one of the main subjects of this volume.

There is no experiment in the whole range of science which would create more curious wonder than the boiling of water and the production of steam, if it were but novel. That water should be put into a close vessel as a heavy fluid, obedient, like all other solids and liquids, to the law of gravitation, and that after a short period of exposure to heat it should burst out as an elastic, bounding vapor, rising and spreading instead of falling, is a phenomenon quite as surprising as the formation of a solid by the mixture of two liquids, or any other marvel of modern chemistry. But it is generally viewed without interest, because it is daily seen, and what little is known about its properties is commonly learned from household tradition, rather than from thought or investigation. Few, however, are so ignorant as not to know that when water has been made hot enough to boil, the heat it continues to receive is employed in converting it into steam, and that this steam has a great expansive power. Now it is this property of expansion which gives steam its mechanical force. The same principle which, on a small scale, causes the cover of the teakettle to rise, will, when steam is generated in larger vessels, and allowed to gather force by accumulation, lift up the most ponderous weights. To the force of this vapor, indeed, there is no limit but the magnitude and strength of the boilers in which it is generated. If steam, however,

come into contact with a cold substance, it is instantly condensed into water, loses its elastic power, and collects in liquid, inert drops upon the substance which has absorbed its heat. How to regulate the expansion and condensation of steam, so as to convert this furious and ungovernable power into a tractable agent, available for the wants of man: how to employ it in lifting weights, or dragging loads, and then to bring it into a liquid inoperative condition, exactly at the instant when it has done what is required, is the problem which, after tasking the energies of successive races of natural philosophers, may be said to have received its solution from the genius of JAMES WATT.

When we examine the ponderous volumes which have been written in explanation of the steam-engine, in its numerous varieties of form and construction—all more or less valuable, and worthy of the engineer's attention—we are surprised that one mechanical contrivance should have found employment for so much ingenuity and skill. No other invention, perhaps, has received so many improvements and adaptations. One-hundredth part, indeed, of what has been written upon it would have been enough to describe many more complicated combinations of mechanical powers. But, though so much has been said on the details of its structure and uses, the steam-engine can still be made the subject of a book intended for the information and amusement of those who have nothing to do with its construction, and who would shun those volumes

of elaborate scientific matters which the mechanist so eagerly collects. If, however, it be remembered that its history could furnish a volume of anecdote and biographical notices of the many illustrious men connected with its manufacture and application, it will not be thought an undesirable topic for a volume addressed to general readers. Nor let it be supposed that the subject is one which is destitute of religious bearings. In the bestowal of this gift upon His intelligent creatures, we may clearly trace the benevolence of God; while in its discovery at a fitting period of the world's history, his providential care is no less clearly apparent. The selfishness, too, which has occasionally perverted an engine, meant to alleviate human toil, into an instrument for increasing it, opens to the thoughtful reader a vein of important reflection; illustrating, as it does, the corrupt principles of the human heart, and the necessity for their counteraction by the gracious provisions of that gospel which is the sovereign remedy for all the ills, individual or social, of man's condition.

The reader would be deceived by the assertion that the construction of the steam-engine, in all its proportions and details, can be easily learned, or that the application of a few hours in studying the best books would enable him to master the subject. Still, principles can be laid down which may serve as the basis for more advanced studies, and explanations can be given which may largely gratify the intelligent reader's thirst for information. Many are ignorant about the steam-engine

because they have had few opportunities of learning. Their inquiries have been met with answers unintelligible to them from the want of some preliminary knowledge, or from the teacher's ambiguity of expression. To this class the following pages will be well suited. Minute descriptions, mechanical details, scientific comparisons of one contrivance with another, would be altogether out of place, and will be avoided. A concise but clear description of the causes and mode of action of the steam-engine is all that can be attempted by the author, and all, it may reasonably be expected, that will be looked for by the reader.

CHAPTER I.

WHAT THE ANCIENTS KNEW ABOUT STEAM AND THE STEAM-ENGINE.

To think more highly of ourselves than we ought to think, is the fault of nations as well as of individuals. In no instance is this more clearly exhibited than in the exaggerated estimate so frequently made of the knowledge and wisdom of our age, by the assumption that all previous generations were absolutely ignorant. It is necessary we should fairly calculate the amount of our knowledge and the extent of our advantages, in order that we may be conscious of our responsibilities; but it may be doubted whether this is always best done by such comparisons as, in complacent mood, we are apt to indulge. The lack of documentary evidence is a strong impediment to a fair judgment of ancient learning and discovery. But, in our estimate of what does remain, we are liable to make erroneous deductions from misconception; for the philosophers of antiquity frequently communicated their knowledge in brief, sententious, emblematical language, which we misconstrue from ignorance of their modes of thought and expression. That the scientific information of the

present day far exceeds that of any other age of which we have explicit records, cannot be doubted; but this gives no authority for the common belief that every discovery of this and the last century was previously unknown. The closer the scientific annals of ancient Asiatic nations are examined, the more powerful is the conviction that many of the fundamental principles of natural science were discovered and applied by the more intelligent castes, and that this is not the first age in which curiosity has been excited, investigation active, and knowledge obtained. Nor is it difficult to understand how truths, once acquired, may have been subsequently lost. Desolating wars, the fall and dispersion of nations, the inroads of the powerful and barbarous upon the wise, the long pilgrimage and laborious settlement of colonists, are sufficient to account for the comparative destitution of science among the nations of antiquity, and especially among the Greeks and Romans, with whose history we are most familiar.

The Greeks, as a nation, were given to pleasure, and their high appreciation of works of imagination and metaphysical subtlety was an impediment to the prosecution of scientific researches. The character of the Athenians, the most polished and learned of this remarkable people, was well described by the apostle Paul, when, standing on Mars' Hill, he addressed them: "Ye men of Athens! I perceive that in all things ye are too superstitious." Nor are their habits less pointedly described in that incidental allusion preceding the report of his oration: "All the Athen

ians, and strangers which were there, spent their time in nothing else, but either to tell or to hear some new thing." This was a bad soil for the growth of experimental philosophy; but there were some even among this people who possessed an amount of scientific knowledge which we should not in modern times have suspected, had the names and works of Euclid and Hero of Alexandria been lost. The former has left a treatise on geometry which is the text-book in all the schools and colleges of Europe, and the other a work on pneumatics, from which we learn that, one hundred and twenty years before Christ, many of the properties of air and steam were understood, and attempts made to apply their mechanical force. Let us see what this Hero, the Alexandrian philosopher, knew about steam and steam-engines:

"When round medical glasses which have long slender necks," he says, "are to be filled with water, the air contained in them is sucked out, and the orifice closed with the finger: they are then inverted in water, and on removing the finger, the water is drawn up into the vacuous space, in contradiction to the usual law of fluids." From this description, which is not sufficiently explicit to inform us whether the tube was of that hair-like bore called capillary, or merely a tube of small dimensions, we learn that the Greeks knew that space could be deprived, partially at least, of air, and that they had observed one effect of atmospheric pressure, if they were not acquainted with the fact that air has weight.

The experiment encourages the belief that external pressure was recognized as a cause; and if so, they were in possession of a principle, the knowledge of which was afterwards lost, and re-discovered in the seventeenth century by Torricelli, an Italian philosopher.

"In this manner," he says, in another place, "air may be rarefied by heat, even as other substances are, for water is changed by fire into air: the vapors from boiling caldrons are nothing else than expanded water taking the form of air, and mists and clouds are nothing else than water raised in the atmosphere by heat, which are partly afterwards converted into air, while portions again descend in rain." Although an exception may be taken to the philosophy here announced, in some particulars, it recognizes the formation of steam by heat, and the property of expansion. In another part of Hero's Pneumatics, elasticity is admitted, as it is also by Aristotle and other authors.

The Grecian theory of earthquakes is a sufficient proof that the force of steam was not undervalued; and so plausible is the hypothesis, that some writers of our own times have adopted it. The ancients supposed earthquakes to be produced by steam generated from water by subterranean heat. Well knowing, as they must have done, the intensity of the volcanic force in rending asunder the solid masses of the globe, raising mountains, and forming islands in the midst of the sea, the philosophers of antiquity must have had an adequate notion of the power of steam, or

otherwise they would not have attributed such violent effects to its presence. But while this is sufficiently evident, there is no reason to believe that any attempt was made to measure its power, or to ascertain the law of its increased expansive force under pressure. Its gigantic energy was known; and without any such reasoning as would now be considered necessary for the advance, not to say the reception of a theory, its presence was admitted to be sufficient to produce earthquake, the most violent phenomenon in nature.

That the Greeks should have had such a vivid conception of the power of steam is so strange that we are led to inquire from what source they obtained it. The question is answered by an author intimately acquainted with the application of steam and the construction of engines. Adopting the hint of M. Arago, he says: "Such notions resulted, not as consequences of any exact or scientific principles, but from vague analogies, derived from effects which could not fail to have been manifested in the arts, such as those which commonly occurred in the process of casting in metal the splendid statues which adorned the temples, gardens, and public places in Rome and Athens. The artisan was liable to the same accidents to which modern founders are exposed, produced by the casual presence of a little water in the mould into which the molten metal is poured. Under such circumstances, the sudden formation of steam under an extreme pressure produces, as is well known, explosions attended with destructive effects. The Grecian and Roman artisans

were subject to such accidents, and the philosophers, generalizing such a fact, would arrive at a solution of the grander class of phenomena of earthquakes and volcanoes." The supposition is ingenious, and by no means an improbable reason why the ancients, as we are accustomed to call them, formed so large an estimate of the energetic power of steam.

The idea of the application of steam as a motive-power was also known to the Greeks, as we learn from Hero. There is a pretty experiment, familiar to most of our readers, which is exhibited by lecturers to show the expansive force of air, and which is also not unfrequently displayed in druggists' shops, as a pleasing ornament or useful fountain. As exhibited in the class-room, it consists of a copper vessel, about half filled with water, the space above the liquid being occupied with highly compressed air. A tube is carried through the vessel, reaching at one end to nearly the bottom of the water, and at the other rising about two feet above the vessel, and terminating in a hemispherical cup. By means of a stopcock a passage is opened through the tube, and the expansive force of the compressed air drives the water upward, producing a fountain, while a ball, previously placed in the hemispherical cup, is supported by the jet. Now this is Hero's experiment, with only a variation in the agent employed, for he used the expansive force of steam instead of compressed air. The vessel containing the water was placed over a fire, and steam was generated, which, issuing from a pipe screwed

into the neck of the vessel, rushed out of the aperture thus provided, and supported the ball in the manner already described. Of the two experiments, Hero's will probably be preferred by our readers.

We have on record an instance of the employment of steam many years afterwards, for a vindictive purpose. Anthemius, the architect of St. Sophia at Constantinople, lived next door to Zeno, and they were at enmity. To annoy and injure his neighbor, Anthemius connected some boilers in the ground-floor of his house with the space between the floors in Zeno's dwelling, and, when in an angry and vindictive humor, he lighted his furnaces, boiled the water, and raised such a force of steam, that his neighbor's floors heaved and cracked under the pressure, to the great alarm and dismay of all who witnessed the scene.

Although Hero's discoveries, if they were his, were only employed in what would now be called philosophical toys, he really constructed a steam-engine, and upon a principle thought worthy of being adopted as a working machine in modern times. A hollow metallic globe was suspended between two pivots, through one of which its interior was connected with a boiler containing water. From the circumference of the globe, upon a circle, two or more hollow tubes were attached, closed at the end, but having a small opening at one side, the opening in each being so made that when the vessel revolved they followed each other in the same direction. The

steam entering the ball escaped through the small openings in the arms, and a rapid rotatory motion was produced, but from what cause may not be at once evident. There is a law in mechanics which says that reaction must always be equal and in a contrary direction to action. When a man runs against another walking in an opposite direction, he drives him forward, but recoils or falls backward himself. So steam, issuing from an aperture, strikes against the atmosphere, and the vessel from which it flows, if capable of motion, is driven in the direction opposite to the course of the steam. If there be many jets of steam, all projected in the same direction, the velocity and force will be proportionately increased.

M. Arago ingeniously explains action and reaction by the selection of a gun as an example. When a fowling-piece is discharged, the rapid vaporization of the powder propels the missile, but the gun itself rebounds and strikes the shoulder of the sportsman. Now here it will be observed, the reaction is in a direction opposite that of the motion. But if the mouth of the gun were closed, and an opening made at the side, the reaction would be sideways; and if the butt end of the piece were so fixed that the gun could move as upon a centre, it would revolve, and if the discharge were continuous, so also would be the rotation. The arms of Hero's machine were constructed in this way, and had a similar motion, the speed and power being increased according to the number of the arms. The same prin-

ciple is adopted in Barker's mill, water being used instead of steam.

This is the first instance on record of the production of motion by steam. The instrument is called an æolipile. The word has been variously spelt, but appears to be derived from two latinized Greek words, *Æoli-pila*, signifying the ball of Æolus—an appropriate designation. Since the time of Hero, the æolipile has been applied for various purposes, but, from its want of power, it deserves to be called a toy rather than a useful engine.

Sir Hugh Plat, in his "Jewel House of Art and Nature," published in 1653, describes an æolipile, which he says is "a round ball of copper or latten, that will blow the fire very strongly, onely by the attenuation of water into air, which device may also serve to perfume with."

Plat, in his "Natural History of Staffordshire," (1686,) gives a description of a steam-generator, and relates its curious connection with a feudal tenure. "There are many old customs in use within memory, of whose originals I could find no tolerable account: such as the service due from the lord of Essington, in this county, to the lord of Hilton, about a mile distant, viz., that the lord of the manor of Essington shall bring a goose every Newyear's Day, and drive it round the fire in the hall of Hilton, at least three times, which he is bound to do as a mean lord, whilst Jack of Hilton is blowing the fire. Now Jack of Hilton is a little hollow image of brass, of about twelve inches high, kneeling upon his left

knee, and holding his right hand upon his head, having a little hole in the place of the mouth about the bigness of a great pin's head, and another in the back about two-thirds of an inch in diameter, at which last hole it is filled with water, it holding about four pints and a quarter, which, when set to a strong fire, evaporates in the same manner as in the æolipile, and vents itself at the smaller hole at the mouth in a constant blast, blowing the fire so strongly that it is very audible, and makes a sensible impression in that part of the fire where the blast lights, as I found by experience, May the 26th, 1680."

In 1629, Branca, an Italian architect, published a work descriptive of a machine which consisted of an æolipile projecting a current of steam upon the floats of a wheel; and the same thing seems to have been done by the Jesuits in China, to amuse the emperor Kanghi, who died in 1722. Père du Halde, in his "History of China," says: "They caused a wagon to be made of light wood about two feet long, in the middle of which they placed a brazen vessel full of live coals, and upon them an æolipile, the wind of which issued through a little pipe upon a sort of wheel made like the sail of a windmill. This little wheel turned another with an axletree, and by that means the wagon was set a running for two hours together; but for fear there should not be room enough for it to proceed constantly forwards, it was contrived to move circularly in the following manner:—to the axletree of the two hind wheels was fixed a small beam, and at the

end of this beam another axletree passed through the stock of another wheel somewhat larger than the rest; and, accordingly, as this wheel was nearer or farther from the wagon, it described a greater or less circle. The same contrivance was likewise applied to a little ship with four wheels: the æolipile was hidden in the middle of the ship, and the wind issuing out of two small pipes filled the little sails, and made them turn about a long time. The artifice being concealed, there was nothing heard but a noise like wind, or that which water makes about a vessel."

Hero, with whom these experiments appear to have commenced, did not always innocently apply his learning or discoveries, and in this respect also he was followed by other ingenious but unscrupulous men. Error is ever ready to receive the assistance of science in imposing on its victims; but science is never so disgraced as when it condescends to help the impostor. The gross idolatrous superstitions of Greece and Rome at no period received the hearty belief of the learned, and yet, from a pride of superior knowledge, and an anxiety to keep the poorer classes in ignorance, they were always ready to assist in making more dense the thick darkness that covered the earth. In the temples of idols the largest and most ingenious of Hero's works were erected, to deceive the people and perpetuate the dominion of a degraded and cruel priesthood. Nor was he ashamed to record the fact, or to describe the mode in which he practiced the deception. In one of these temples he so contrived

his apparatus as to convey wine through pipes from vases to the hands of two figures standing by the altar of sacrifice, and by the same agent, steam, produced "sibylline sounds" from the mouth of a golden dragon. In another temple, figures were made to dance round an altar by being attached to a large drum, revolving by the force of issuing steam. By such contrivances as these, which in the present day would scarcely amuse the idle spectators of a puppet-show, the volatile Greek and the brutal Roman populace were held in obedience to the priests of false gods, and confirmed in the indulgence of all those sensual and unholy practices, so conformable to the natural depravity of the human heart, and which were so intimately bound up with the rites of idolatry.

Arago, in his "Life of Watt," gives another instance of the adaptation of scientific discovery to the purposes of deception. "Ancient history," he writes, "has informed us that on the banks of the Weser, the god of the Teutones of old sometimes showed himself unpropitiously by a sort of thunder-clap, immediately succeeded by a cloud, which filled the sacred enclosure. The statue of the god Busterich, discovered, it is said, in the course of excavation, clearly shows the method by which the pretended miracle was affected. The god was of metal: the head was hollow, and contained an amphora (about nine English gallons) of water: wooden plugs closed up both the mouth and another opening above the forehead: live coal, dexterously placed in a

cavity of the skull, gradually heated the liquid. Very soon the steam generated forced out the plugs with a loud report: it then escaped with violence in two streams, and raised a thick cloud between the deity and his stupified worshippers. It would appear that in the middle ages some monks found their account in this invention, and that the head of Busterich has performed its office before other than Teutonic multitudes." Evidences are too numerous and too strong to leave a doubt of the frequent use of physical phenomena by the Roman Church as miraculous interventions of God and spiritual beings. A priesthood driven to such subterfuges to maintain a character for sanctity must be in the deepest state of degradation. It is only for a time, however, that a religion can be supported by such hollow pretences, and hold an ignorant people in mental thraldom and spiritual darkness. The influence of habit and the authority of prescription are not easily broken, it is true, more especially when surrounded with such threats, temporal and spiritual, as those with which the Roman Church supports its interests. But deeply as that false Church has degraded the nations which have listened to its pretended miracles, (as much by the atheism it has produced among the educated, as by the unthinking belief and fanaticism engendered among the lower orders,) it is consoling to know that the day will come when the simple truths of Christianity will break down all forms of deception, and Christ shall live and reign in the hearts of a people who shall be his true and spiritual worshippers.

CHAPTER II.

WHAT WAS DONE TOWARDS THE CONSTRUCTION OF A STEAM-ENGINE BEFORE THE TIME OF JAMES WATT.

THE importance to which the steam-engine has risen during the present century, has given so much interest to the history of its invention and progressive improvement, that almost every nation in Europe has presented a claim to the honor of having done something towards its production. It was not, perhaps, to be expected that such a controversy should have been carried on, during the early part of this century, without the display of some national animosity. The minds of men had been too deeply scarred by the iron hoof of devastating war to permit a peaceful examination of even a question of scientific priority. The claims of honorable competition were viewed with jealousy, and the prejudices of some pugnacious minds even tainted the streams of scientific history. This rancorous and litigious spirit has been in a great measure subdued, however, and men may now discuss the question without being charged with national animosity or personal hatred.

With these disputes, however, we shall no further concern ourselves than may be necessary for a clear and impartial statement of the history of the steam-engine, which we shall, with all candor, endeavor to collect from the works of those who have engaged themselves in scientific discovery or mechanical invention.

The first claim to the honor of inventing a steam-engine is presented by Spain in behalf of Blasco de Garay, a sea-captain, who, in 1543, petitioned the Emperor Charles V. for an opportunity to make trial of a machine by which he could propel vessels without oars. The petition was granted, and a vessel of two hundred tons' burthen was placed at his disposal and under his charge. In her he fixed his machinery, and a trial was made in the port of Barcelona, on the 17th of June, 1543. As he took the precaution to conceal his machinery, the only information obtained about it was, that he had a large boiler, to which wheels were somehow attached on both sides of the vessel, and that by their rotation the latter was propelled. The experiment was successful, and the commissioners, with one exception, reported the speed to be a league an hour. For some reason, not now to be discovered, the performance was viewed less favorably by Ravaga, the king's treasurer, who stated that the machinery was complicated, the boiler dangerous, and the speed not more than two leagues in three hours. In spite of this opposition, however, the expenses of the experiment were paid by the government, and the inventor was rewarded, but

the machinery was taken out of the vessel, and no more was heard of the discovery. The nature of the force employed can only be conjectured, and the principle and action of the contrivance are so entirely unknown, that it would be idle to speculate upon the amount of honor to be awarded to Blasco de Garay.*

France next introduces us to two authors, for whom she claims honorable notice. Flurence Rivault, a gentleman of the bedchamber to Henry IV., and preceptor to Louis XIII., published in 1605 a work on Artillery. In this book he states, that if a bomb-shell be one-third filled with water, and then plugged, it will burst with great violence if placed over a fire. He seems to have been aware that this explosion was produced by the accumulation of steam; but supposing him to have been the first to have discovered the fact, it still remains a doubt whether he knew it to be the effect of its expansive force.

Solomon de Caus was architect and engineer to Louis XIII., and his merits in connection with our present subject have been warmly advocated by M. Arago, and other modern French authors. In the year 1612, he entered the service of the elector palatine, who married the daughter of James I. With that prince he went to England, and was engaged by the Prince of Wales in the decoration of his gardens at Richmond. In 1615,

* It is proper to mention, that some writers question the genuineness of the documents on the strength of which this interesting episode in Spanish history rests.

he published a work on Motive Forces, and this book became the source, two hundred years after, of bitter dispute and angry contention. M. Arago blames the English authors for disallowing the claim of De Caus to the honor of a share in the invention of the steam-engine, and attributes their opposition to the desire of monopolizing for their native country all the credit of the discovery. Such a motive would be as dishonorable as foolish; but we can see no evidence for the imputation.

The bursting of a ball of copper by the pressure of confined steam, which was one of De Caus's experiments, had been previously performed by Flurence Rivault; and in the temple of the god Busterich, as has been shown in a previous chapter, the fact was as well known to the initiated as to the engineers of the seventeenth century. The experiment on which his claim to a discovery rests, is that of forcing a column of water up a tube fixed in a copper vessel, by the united expansive power of air and steam. But, after all, the question is, whether he, like many before him, believed the extraordinary force thus developed to arise from the mingling of steam with the air in the vessel, or whether he was conscious of the great expansion of steam and the increase from pressure. In one of his descriptions, he uses the following terms of explanation:—"The violence of the vapor which causes the water to rise proceeds from the same water, which vapor goes out from the cock after the water with great violence." From this

passage, which at the best is most remarkable for its obscurity, M. Arago deduces that Solomon de Caus understood the property of elasticity to belong to steam, irrespective of the air with which it is mixed. For many centuries, the expansive power of air, when acted upon by heat, had been known. This fact, we believe, is admitted by all authors; and to us it seems probable that the elasticity of steam was also discovered, and that Hero himself was acquainted with the property.

The first of a long catalogue of inventors presented by England is Edward Somerset, marquis of Worcester. This nobleman having engaged himself with the royalist forces in the parliamentary wars, was taken prisoner and confined in Ireland, from which place he made his escape, and joined the king, Charles II., in France. Venturing again into England on a secret embassy, he was seized in London and committed to the Tower, from which he was not released till the restoration of the monarchy. In 1663, he published a work called "A century of the names and scantlings of such inventions as at present I can call to mind to have tried and perfected, which (my former notes being lost) I have, at the instance of a powerful friend, endeavored, now in the year 1655, to set down in such a way as may sufficiently instruct me to put any of them in practice." In this book there are many extravagant propositions, but there are also many useful inventions, which have been adopted and valued in our own times, not, however, from Worcester's descriptions, for they are so vague and unsatisfac-

tory that a suggestion is all that can be obtained from them. His sixty-sixth invention is a steam-engine for raising water, which he thus describes: "I have invented an admirable and forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be, as the philosopher terms it, *infra sphærum activitatis*, which is but at such a distance. But this way hath no bounder if the vessel be strong enough; for I have taken a piece of whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole, and making a constant fire under it: within twenty-four hours it burst, and made a great crack. So that having a way to make my vessels, so that they are strengthened by the force within, and the one to fill after the other, I have seen the water run like a constant fountain stream forty feet high. One vessel of water, rarefied by fire, driveth up forty of cold water, and a man that tends the work has but to turn two cocks; that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

Lord Worcester has given no description of the engine he invented; but as it is easy, with our present knowledge of steam and its applications, to design one meeting all the conditions of his statements, the lack of precise information has

been supplied with conjectures by his commentators. There is one important particular in which he is distinguished from all the inventors who preceded him. It will be observed that in the experiment of Solomon de Caus, the effect obtained was immediately connected with the vessel in which the steam was generated; but in Worcester's engine the steam was conducted from the vessel in which it was generated to the work it was required to perform. This is the only principle which could have led to the invention of the present steam-engine; and as far as we can understand the evidence to be collected from the works of inventors, who too often rather hint at their discoveries than describe them, the history of that mighty contrivance begins with the Marquis of Worcester.

M. Arago's remarks upon the claims of De Caus and Worcester, though somewhat captious, are worthy of notice, as representing the opinions of French authors upon the origin of the steam-engine. "You have been," he says, "made acquainted with the invention for which France and England have contended—as in times of yore seven cities of Greece, in their turn, arrogated to themselves the honor of having been the birth-place of Homer. On the other side of the channel, all have concurred in attributing the merit of it to the Marquis of Worcester, of the illustrious house of Somerset: on this side of the strait we maintain that it belongs to an humble engineer, almost altogether overlooked by biographers, viz., Solomon de Caus.

"The marquis, being seriously implicated in the intrigues in the latter years of the reign of the Stuarts, was imprisoned in the Tower of London. One day, as the story goes, the lid of the pot in which his dinner was cooking suddenly rose. What can a man do in such a case but think? The marquis then thought about the strange phenomenon he had just witnessed. Then it occurred to him that the same force which had lifted the lid might become, in certain circumstances, a useful and convenient power. After regaining his liberty, he explained in 1663 the means by which he thought he could put his idea in practice. These means are, in all their essential points, the bomb-shell half full of liquid, and the ascending vertical tube."

Although we have no evidence that Sir Samuel Morland did any thing to improve the mechanical construction of the steam-engine, his name must not be omitted in a historical description of the contrivance. His reputation may not have extended to the circle of general readers, but he is well known to those who have studied the progress of hydraulic engineering. He was appointed master of the works by Charles II., in the year 1680, and was the inventor of several ingenious scientific contrivances. His right to be mentioned in connection with the progress of the steam-engine, is founded upon a passage in a manuscript work, written in French, and preserved in the British Museum. "Water," he says, "being converted into vapor by the force of fire, these vapors shortly require a greater space (about 2000

times) than the water before occupied, and sooner than be constantly confined would split a piece of cannon. But being duly regulated according to the rules of statics, and by science reduced to measure, weight, and balance, then they bear their load peaceably, (like good horses,) and thus become of great use to mankind, particularly for raising water, according to the following table, which shows the number of pounds that may be raised one thousand eight hundred times per hour to a height of six inches, by cylinders half filled with water, as well as the different diameters and depths of the said cylinders." This is, as far as we know, the first attempt ever made to measure the expansive force of steam and its working power, and it is singular that Morland's experiments should have brought him so near the truth. M. Arago states that Professor Besson, of Orleans, attempted to determine the relative bulk of water and steam, and recorded his experiments and their results in a treatise published in 1569. This work we have not been able to obtain; but it seems strange that he should have pursued such a study without detecting the expansive power of steam. How far his discoveries may interfere with the several claims of the authors already mentioned we do not know, or how much Morland may have been assisted by him in his successful attempt to measure the expansive force. Evelyn describes an interview he had with the English engineer in 1695, and though then blind, he was surrounded with his mechanical inventions. He died in January, 1696.

Denis Papin was born at Blois, in France, about the middle of the seventeenth century, and, having prepared himself for the practice of medicine, took his degree at Paris. In consequence of the revocation of the Edict of Nantes, he was compelled to leave his native country, and take refuge in England, where he became acquainted with that devout Christian man and profound philosopher, Robert Boyle, and assisted him in some of his experimental researches. In 1681, he was elected a fellow of the Royal Society, and some time after received the appointment of professor of mathematics at the University of Marburg, under the patronage of the Landgrave of Hesse, and in that city he died.

To this ingenious philosopher we are indebted for the first idea of applying an elastic fluid as a force for the motion of a piston working air-tight in a cylinder. Being well acquainted with the expansive power and pressure of atmospheric air, he perceived that it would be easy to force the piston up a cylinder by the elastic force of that fluid acting under it, and he also knew that if he could then remove the air from beneath the piston, the atmospheric pressure would force it down again. How to obtain this vacuum was the only difficulty. If the pressure of the external air upon the outer surface of the piston is at the rate of fifteen pounds for every square inch, and if it remain at the top of the cylinder, in opposition to gravity, only because the pressure of the external air is counterbalanced by that of the internal, it is evident that when a part of the air is removed

from beneath the piston, and an aperture is left for the escape of the remainder, the piston must fall, and that with a force proportioned to the difference between the external and internal pressure. All this was known to Papin, and he sought anxiously for some method of discharging the air from the cylinder when it had lifted the piston. His first device was the application of air-pumps worked by a water-mill. This contrivance he laid before the Royal Society. It was but a crude development of a noble idea, but whether it was so esteemed by that learned body we know not. The probability is, that the Society had no thought beyond the slow, unsatisfactory model he exhibited, and met his communication with objections that condemned his machine, if they did not discourage him. Subsequently he appears to have attempted the expulsion of the air by the explosion of gunpowder; but this failed to accomplish his object. Another thought rose in his mind: it was a final one, for in imagination he had before him a complete and perfect steam-engine. In a work published at Cassel in 1695, written in his native tongue, he says: "I have endeavored to attain this end (the production of a vacuum in a cylinder) in another way. As water has the property of elasticity when converted into steam by heat, and afterwards of being so completely re-condensed by cold that there does not remain the least appearance of this elasticity, I have thought it would not be difficult to work machines in which, by means of a moderate heat, and at a small cost, water might produce that perfect

vacuum which has vainly been sought by means of gunpowder." Now, although Papin did not succeed in fully developing the practical operation of his most important suggestion, we may claim for him the honor of laying the foundation of that success which attended the study of those who followed him. In driving from the shores of France, under a fiery Popish persecution, this master-mind, his country lost all claim to the honor of appropriating the labors of the only one of her sons who did any thing worthy of record towards the invention of the steam-engine.

M. Arago seems to coincide, in a great measure, with this opinion. "It is Papin," he says, "whom France will have to thank for the honorable place which she can claim for herself in the history of the steam-engine. Yet the just pride which his success may teach us to feel will not be altogether unmixed. We shall find that the claims of our countryman occupy a place only in the records of foreign lands: that his principal works were published beyond the Rhine: that his liberty was menaced by the revocation of the Edict of Nantes: that it was in a sorrowful exile that he enjoyed, for a brief period, that blessing which studious men most anxiously desire—tranquillity of mind."

Not long after the publication of Papin's book, one Thomas Savery obtained a patent for a steam-engine of a peculiar construction, to raise water into a vacuum produced by the condensation of steam. The form of his engine, and other circumstances, leave little doubt that he was unac-

quainted with Papin's suggestion. According to his own account, he was led to apply the condensation of vapor as a means of obtaining a vacuum by an accidental circumstance. Being on one occasion in a tavern, he called for a flask of Florence wine, and, having drunk its contents, threw the bottle into the fire. He might have been in an indolent yet thoughtful humor, a musing state, in which the intellect is peculiarly open to sudden impressions, and the will ready to follow its dictations. His eye fell upon the unbroken flask, in which a little wine remained, and he saw that steam was rushing from its mouth. Hastily covering his hand with a thick glove, he plunged the neck into a basin of cold water standing near, and the flask was almost instantly filled with the liquid: the steam had been condensed, a vacuum had been formed, and the atmospheric pressure had forced the water into the empty space. This will perhaps be called an accidental discovery. Was it so? Certainly not! How many men in this same tavern had done the same act, seen the same result, and regarded it with indifference! Who among them had thought of plunging the hot flask into cold water? It was an experiment suggested by previous knowledge and thoughtful investigation, and when the fact was discovered, the application was at hand. Few scientific discoveries are accidental. Galvani's observation of the muscular contraction of a frog by the contact of dissimilar metals united at one edge, was accidental; but, in the correct sense of the word, he cannot even be said to have discovered the fact,

for he did not seek it. Hence he has been deprived, in our own day, of the application of his name to an important and now well-developed branch of physical science, and that of Volta, an acute experimentalist, the true discoverer, has taken his place. Savery deserves the name of a successful experimentalist, and not the less so because he was able to seize an accidental condition for the purpose of trying his theory—a theory for which he deserves great praise, whether it was the result of long-continued thought, or the produce of the phenomenon which he at the instant made available to prove its truth. No sooner was the experiment made than Savery perceived that he might discard the piston and sucker of the common pump, and obtain as good a vacuum by filling a cylinder with steam, and then condensing it: that the atmospheric pressure would force the water to the same height in one case as the other; and that the elastic force of steam, ambiguously hinted by Worcester and others, might then be employed to force the water, by successive stages, to any height required. All these thoughts were suggested to Savery, for he applied them in the construction of his engine, which was a mechanical arrangement suited for the combination of all these principles.

It is difficult to convey an accurate perception of the mechanical contrivance without the assistance of a diagram; but a lineal representation, on the other hand, is of comparatively small value to the majority of persons without a detailed de-

scription. It is not necessary to spend much time in minutely examining Captain Savery's engine, our present object being to trace the growth and development of the majestic contrivance, rather than to sketch the protean and often grotesque forms it assumed before it became a really useful servant to mankind. All the information required by our readers may, we think, be easily communicated in a verbal description, with a little care on our part and as much attention on theirs. The principal objects Savery had in view were, to raise water "for turning all sorts of mills," to supply water to towns, and to drain fens, marsh-lands, and mines. For these purposes the household and force-pumps had been long used, and found to be, in many situations, ineffective, and in all, laborious, slow, and consequently expensive. In the common pump, water is raised by the pressure of the atmosphere into a space from which the air is more or less perfectly discharged by the repeated motion of a piston in a cylinder. At every stroke of the piston a certain portion of the air is withdrawn; but, in consequence of its expansive force, that which remains always fills the same space, the density, however, decreasing, and with it the pressure. The external atmosphere being relieved of a counterbalancing force, drives the liquid higher and higher up the pump-pipe and cylinder, until it attains a height at which it balances the atmospheric pressure. Savery's notion was, that this vacuum might be better produced by the condensation of steam than by the action of a pump.

"His engine consisted of two distinct principles: raising water, in the first place, by the pressure of the atmosphere forcing it into a vacuum formed by the condensation of steam; and, in the second, by the expansive power of steam. The steam from a detached boiler was let into a vessel called a receiver, and, having driven out the air, was condensed by the effusion of cold water, and a partial vacuum was formed. A communication being then opened with a suction-pipe twenty-four feet in height, the lower end of which was placed in a cistern or reservoir of water, that water was forced upwards by the pressure of the atmosphere into the receiver. When this was nearly filled, the communication with the suction-pipe was shut off, the steam was reädmitted into the receiver, and, by its expansive power, forced the water contained in it up an ascending, or, as the inventor called it, a force-pipe. The second operation is similar to that indicated by Solomon de Caus, and not only indicated, but perhaps practiced by the Marquis of Worcester. The prior operation, that of raising the water into a vacuum formed by the condensation of steam, we believe to have been original with Savery; for although Papin had described the principal in the *Acta Eruditorum* of Leipzig for 1690, and in a French work published five years later in Cassel, he applied it in a different manner, and there is no proof, or even surmise, of its having been known to Savery when he invented his engine in 1696, or perhaps sooner."

From the year 1698 Papin was engaged in

making experiments with a view to the construction of an engine upon the principle we have already mentioned as his discovery, in which he was greatly encouraged by the Landgrave of Hesse Cassel. In this enterprise he had frequent communications with Leibnitz, who, in a letter dated the 6th of January, 1705, asked his opinion of Savery's engine: "I saw at once," he says, "that the English machine and that of Cassel were founded upon the same principle." With a natural and perhaps well-founded regard to his own invention, he exhibited no mean jealousy of Savery, but speaks of him and his invention in a candid and manly spirit: "What I say here, is not to give room for believing that Mr. Savery, who has since published this invention in London, is not actually the inventor. I do not doubt that the same thought may have occurred to him as well as to others, without having learned it elsewhere." Belidor, the author of a celebrated work on Hydraulics, does not give a flattering opinion of Papin's engine: "Whatever he may say, it is very far from being equally ingenious and complete with that of Mr. Savery, which possesses the advantage of having within itself all the movements it requires, without any one touching it; whereas the other cannot act without the help of several men, one of whom at least is required to give his work uninterruptedly with contrivances which render this machine as imperfect as that of Savery is complete."

"When a comparison," says Mr. Farey, "is made between Captain Savery's engine and those

of his predecessors, the result will be in every respect favorable to his character as an inventor, and as a practical engineer: all the details of his invention are made out in a masterly style, and accidents and contingencies are provided for, so as to render it a real working engine; whereas De Caus, the Marquis of Worcester, Sir Samuel Morland, and Papin, though ingenious philosophers, only produced mere outlines, which required great labor and skill of subsequent inventors to fill up, and make them sufficiently complete to be put in execution."

Savery's engine seems to have been brought into frequent if not general use, for he speaks of the difficulty he had at first with the workmen, and of their having by practice obtained accuracy and skill, so that "they bound themselves to deliver the engines exactly tight and fit for service, and such as he dare warrant them to every one that has occasion for them." It is, however, probable that they were chiefly used in raising water for gardens and domestic purposes. Bradley, in a work on Planting, published in 1718, after the death of the inventor, speaks of "the wonderful invention of Mr. Savery;" and adds, "It is now six years since Mr. Savery set up one of them for that curious gentleman, Mr. Balle, at Camden House, Kensington, near London, which has succeeded so well that there has not been any want of water since it has been built, and, with the improvements since made to it, I am apt to believe will be less subject to be out of order than any engine whatever."

Notwithstanding the great ingenuity exhibited by Savery in the construction of his engine, it was found to be in many respects defective, and insufficient for the drainage of fens and mines. Several improvements were consequently made in it to meet the difficulties as they arose. Both Desaguliers and Smeaton studied its operations, and introduced important alterations. To the former we are indebted for the application of the safety-valve to the boiler, although the invention is, we believe, due to Papin, who applied it to a boiler intended for digesting bones, but Savery had not availed himself of it in the construction of his engine. In consequence of this neglect, there was no means of estimating the pressure of steam in the boiler, and it must therefore have been always liable to accident and explosion. The safety-valve is a loose metallic or other disc, fitting air-tight into an aperture of the boiler. According to the force of steam required, it is loaded with weights, and above the pressure so regulated the steam cannot rise so long as the valve works properly, any additional force being immediately relieved by the passage of steam through the opening. As the application and removal of weights was found to be inconvenient and troublesome, a lever was applied with a weight sliding upon it, so that with this simple arrangement an increase or decrease of pressure could be instantly obtained. This contrivance is still applied to the boilers of stationary engines.

The term "horse-power" is in general use as an estimate of the working effect of steam-engines.

It was first applied by Savery, and, considering the purpose for which the contrivance was introduced, a more judicious mode of calculation could not have been adopted. The object of all the early steam-engine inventors was to obtain a more effective means of raising water than they possessed in the use of the common hydraulic pump. None of them appear to have thought of any other application. The idea of converting the perpendicular into a rotatory motion, and of applying it to drive machinery, was not suggested. It was for draining fens and mines, and for working the pumps of mills, the improvement was required; and as the work was always done by horses, it was convenient to estimate the power of the engine by a comparison with the work before done by those animals. The selection of this mode of calculation was, indeed, scarcely optional, for when a maker received an order to construct an engine, it was always accompanied with the condition that it should be equal to the work of a specified number of horses. For many years, however, there was no fixed principle: every maker calculated the horse-power according to his fancy or interest, and engines constructed at different manufactories, supposed to be equal in effective work, were found to have very unequal power. Some efficient standard of comparison was required, and this could only be obtained by rejecting the term "horse-power," or by giving it some distinct and universally recognized meaning. As there was a good reason for retaining a term which gave a means of cal-

culating an unknown force by a comparison with one generally understood by those who required the engine, and as it was as convenient a designation as any that could be invented, it was retained by universal consent. There was not, however, the same unanimity of opinion as to the mechanical force equivalent to the power of a horse. According to the experiments and calculations of Smeaton, one of the most scientific and successful engineers England has produced, a horse of average strength, working eight hours a day, exerts an efficient power equal to the raising of 22,916 lbs. one foot in height per minute. Desagulier estimated the power of a horse, under the same circumstances, at 27,500 lbs. per minute. Boulton and Watt made experiments upon the strength of some of the powerful, well-fed horses of the London breweries, and their estimate was that the average force of these animals might be considered equal to the elevation of 33,000 lbs. through one foot per minute. This calculation has been adopted by common consent, and is the force now designated a horse-power by all mechanical engineers.

Savery obtained a patent for his engine in 1698, and for a time hopes were entertained that it would meet the requirements of the age. This expectation was soon disappointed: its inapplicability to mining operations was proved, and doubts were thrown upon the efficiency of the principle he had adopted. Thomas Newcomen, an ironmonger or blacksmith, or perhaps both, living at Dartmouth, in Devonshire, having fre-

quent occasion to visit the tin mines of Cornwall, was made acquainted with Savery's engine, and, by the information of others, or by his own observations, with the cause of its inefficiency. In association with John Cawley, a plumber and glazier of the same town as himself, he commenced a series of experiments, and at last designed and constructed a new engine. It seemed to him suitable for the accomplishment of all that was required, but there was a difficulty in the way of its public introduction, for in carrying out his design he was compelled to employ Savery's method of producing a vacuum by the condensation of steam, which could not be done without an invasion of the patent-right. This difficulty, however, was overcome. Savery joined the adventurers as a partner, and, in 1705, a patent was taken out for their joint benefit. But the public introduction of the invention was from some cause delayed till the year 1711, when the first atmospheric engine was made.

Newcomen's engine was a great improvement upon all previous designs, and yet the improvement was in mechanical arrangement rather than in the discovery of any new principle. This will be observed by the reader in following our description of it, but the fact in no degree detracts from the merits and ingenuity of the inventor. As his principal object was to discover a better means of draining mines, he, with great judgment, resolved to retain the pumps as then employed, and to confine his attention to a better means of working them. The adoption of this

resolution led him to success, after many failures and disappointments, and established his reputation as the predecessor of Watt. Otto de Guerick had shown the application of a piston working in a cylinder as a mechanical arrangement in his air-pump. Papin had suggested it for a steam-engine, and its action was well known in the common hydraulic pump. Fixing a beam, suspended at its centre, so that it could move freely on an axis, he attached the pump-rod, by a chain, to one of the curved ends, commonly called arch-heads, and to the other side the piston-rod of the steam-engine. This arrangement will be readily perceived, from its general resemblance to the present form of beam-engines. With this mechanical adaptation, he demonstrated the problem Papin had been unable to solve. The means of obtaining an upward motion of the piston had been suggested—it was to be effected by the expansive power of steam introduced at the bottom of the cylinder. The downward stroke was to be produced by atmospheric pressure, but this could not be effected without condensing the steam that had raised it. To accomplish this object, in which all other mechanists had failed, he surrounded the cylinder with a casing, leaving an interval between them, which, when required, was filled with cold water. An accident led to the adoption of a better plan. It was one day observed that the engine suddenly increased its speed, and worked with more regularity. Upon examination it was discovered that, in consequence of a defective casting, the water spouted

through a small hole into the cylinder, and rapidly condensed the steam. A tube was then laid on from a suitable reservoir into the bottom of the cylinder, and water was injected into it; but, to prevent accumulation, a valve, opening outward, also at the bottom of the cylinder, was introduced to draw off the injected water when the vacuum had been formed. This removed one principal impediment to the effective working of a steam-engine. But it must be observed, that the expansive force of the steam in the cylinder and the pressure of the external atmosphere are supposed to be equal, so that when the steam is admitted under the piston, it will remain, as it were, indifferent to rest or motion, an unstable equilibrium being produced by the opposing equal forces. To give a preponderating power, the pump-rod was made heavier than the piston and rod of the engine. For the working of the engine two valves were necessary, and these were to be alternately opened and closed. One was to admit steam, the other cold water, into the cylinder. The regulating valve, for the introduction of steam, was opened when the piston was at the bottom of the cylinder, the condensing valve when it was at the top. The regulation of the valves was intrusted to youths, who were called cock-boys. One Humphrey Potter, a shrewd lad, tired of his monotonous employment, and anxious to join some companions at play, devised a plan by which his labors could be dispensed with, and, as he probably thought, his absence be undiscovered. For this purpose he connected the

levers by which the valves were opened and closed to the beam with strings, in such a way that the beam itself performed his work without detriment to the motion of the engine, and greatly to the convenience of the ingenious boy. As soon as the contrivance was observed, the strings were removed, and a bar called a plug-frame was introduced in its place.

Surtzer, the author of a work on Hydraulics, published in 1729, speaks in terms of high praise of Newcomen's atmospheric engine. "It is," he says, "the beautifullest and most useful engine that any age or country ever yet produced." And this praise was at the time well deserved. Desagulier, however, attributes the success of the contrivance more to chance than to knowledge and skill. "After many laborious attempts," he says, "they succeeded in making their engine work; but not being either philosophers to understand the reason, or mathematicians enough to calculate the power and proportions of the parts, they very luckily, by accident, found what they sought for." This is, at the best, an ill-natured judgment, and its truth may also be doubted. Newcomen had been in communication with Dr. Hook on the subject, and the advice he received from him is an indirect proof that he was not altogether ignorant of science. This correspondence must have been before 1703, in which year the Doctor died, so that the inventor is chargeable with both idleness and incapacity, if he had not made himself a philosopher equal to the requirements of the age in which he lived, by the time

he completed his work and obtained his patent. That he was an indifferent mathematician is probable, for the improvements subsequently made in its construction prove that the proportions of the several parts had not been calculated. With the exception of some important alterations made by Mr. Beighton in 1718, the engine remained for fifty years in nearly the same state as it came from the hand of the inventor. If this fact does not add to the reputation of Newcomen, it is at least a bar to the reproaches of his contemporaries. Nor must it be forgotten that we are indebted to him for the practice of condensing steam by an injection of cold water, and for the expulsion of the condensing water and air by the injection of steam—which processes are still adopted by the engineer—and for the introduction of the beam, as well as the general form of the engine.

Some improvements, both in arrangement and construction, were made in 1759, by James Brindley, the engineer who designed and constructed the Duke of Bridgewater's canal. In 1772, Smeaton directed his attention to the engine, and with great care calculated the proportions of its parts; and, by his skill, perseverance, and genius, it remained in use long after Watt had made his first brilliant discoveries, and established his reputation as the Archimedes of the Christian era.

Thus, by slow degrees, was this wondrous agent gradually prepared, ripening from a mere philosophical toy into a useful and important instrument of industry. Although we are still upon the very borders of the subject—the chief im-

provements in the steam-engine having been effected by the individual whose career forms the subject of our next chapter—it is interesting to cast our eye back to the days of Hero, and to contemplate the successive struggles and achievements of the inventors who followed in his track. In such a retrospect, the wondrous powers of the human mind are effectually displayed. The instinct of the bird that builds its nest—of the bee that constructs its cell—is wonderful indeed; it is, however, stationary and stereotyped: while man's intellectual powers are ever varying, and advancing from one triumph of skill to another. Is it likely, we may ask, with an eloquent writer, that a being so endowed is to sink into annihilation in a few short years—that the immaterial agent which works within, and employs eyes and fingers only as instruments for doing its incalculably various tasks, should cease to exist when it leaves its present dwelling and lays aside its present tools? No, it must live when all the material triumph, which science has achieved—when every object that now delights the senses—when all the productions of art throughout the world, and all its mountains, rivers, and seas, shall have passed away. The thought of such an endless existence is, indeed, an overpowering one. Has the reader ever pondered it aright? Well might the great Teacher ask the question, "What shall a man give in exchange for his soul?" There is nothing that he can give.

CHAPTER III.

THE EARLY LIFE AND PURSUITS OF JAMES WATT.

THE slow and halting steps of scientific discovery and mechanical invention, from the time of Hero, the Alexandrian, to the commencement of the eighteenth century, are strongly contrasted with the bold and majestic strides which have since distinguished their progress. With difficulty the painfully elaborated thought gave birth to an isolated fact, which neither the discoverer nor his compeers had invention, skill, or knowledge enough to apply to any effective practical purpose. As a twilight, however short, is always the transition between night and day—for darkness and light cannot come into contact—so indistinct perceptions and feeble efforts are the conditions which must intervene between ignorance and knowledge, indolence and enterprise, whether in individuals or societies. We are not, then, surprised that the sixteenth and seventeenth centuries should have been spent by the most intelligent and observing scientific minds of Europe in the discovery of the pressure of the atmosphere and the elasticity of steam; nor that the inventive faculty of the mechanist should have been ex-

hausted in awkward, ineffective attempts to apply them as motive forces in mechanical arrangements. Far more strange and anomalous would it have been, if, after such a lengthened period of mental inaction and blindness, dependence on authority, and attachment to sensual pleasures, as distinguished the despotic rule of the Roman Church in England before the Reformation, one or more great minds had made the discoveries and effected the revolution which distinguished the eighteenth century. If Watt had lived in the days of Worcester, the same benefit would not have been received by society from his vast intellectual power and indomitable perseverance. God, in the course of his providence, usually effects his designs by slow, often by imperceptible means, and always introduces his agents at the times most suited to the development and application of their powers. In no secular event is this more remarkably exhibited than in the state of science and the mechanical arts, as well as the growing wants of society, when Watt made his appearance as a philosophical investigator and inventive mechanician. The result of his labors established not only a new scientific era, but also an improved commercial and social condition, destined by God to accomplish important designs in the arrangements of his providence.

Speaking of Mr. Watt, Lord Jeffrey says: "This name, fortunately, needs no commemoration of ours; for he that bore it survived to see it crowned with undisputed and unenvied honors, and many generations will probably pass away

before it shall have gathered all its fame. We have said that Mr. Watt was the great improver of the steam-engine; but, in truth, as to all that is admirable in its structure, or vast in its utility, he should rather be described as its inventor. It was by his inventions that its action was so regulated as to make it capable of being applied to the finest and most delicate manufactures, and its powers so increased as to set weight and solidity at defiance. By his admirable contrivances, it has become a thing stupendous alike for its force and flexibility, for the prodigious power which it can exert, and the ease, and precision, and ductility with which it can be varied, distributed, and applied. The trunk of an elephant, that can pick up a pin, or rend an oak, is as nothing to it. It can engrave a seal and crush masses of obdurate metal before it; draw out, without breaking, a thread as fine as gossamer, and lift a ship of war like a bauble in the air. It can embroider muslins, and forge anchors; cut steel into ribbons, and impel loaded vessels against the fury of the winds and waves."

James Watt was born at Greenock, in Scotland, on the 19th of January, 1736. His descent has been traced back to the time of his great-grandfather, who was a farmer in the county of Aberdeen; but engaging, like many others of his countrymen, in the civil wars of the period, he fell in one of the battles of Montrose. He left one son, Thomas, who had not only to deplore the loss of a parent, but also of the little patrimony which ought to have descended to him, but which

was, according to custom, unmercifully confiscated. This youth, an orphan, thrown cruelly on the charity of the world—a cold and heartless source of dependence—was received and nurtured by some distant relatives. Applying himself to study, he became a competent teacher of mathematics and navigation, and in time established himself at Greenock in that capacity. His residence was in the adjoining burgh of Crawford's Dyke, where, in after years, he held the office of bailie or chief magistrate. He died in the year 1734, in the ninety-second year of his age.

Thomas Watt had two sons, John and James: John, the elder, followed his father's profession, and died at the age of fifty, three years after his father. He seems to have added the profession of a surveyor to his other employments, for he left a map of the Clyde, which was afterwards published by his brother.

James, the younger brother, was a builder, merchant, and ship-chandler, and for many years carried on a successful trade; but towards the end of life he was unsuccessful in his speculations, and lost the greater part of his property. He had two sons, John and James. John was drowned in 1762, at the age of twenty-three, when on a voyage from Greenock to America, in one of his father's vessels. The father died in 1782, eighty-four years of age, his life being spared to witness, in part, the success, and enjoy the honors of the son, who was then deeply engraving his name in the records, not only of his country, but of all nations, for all time.

James Watt, like many other distinguished men, was indebted to his mother, whose maiden name was Muirhead, for his early education. Being of exceedingly delicate constitution, the greater part of his time was spent at home; much of it as an invalid, confined to his own room. When sent to school, his attendance was irregular, and, with such assistance as his father could give him in writing and arithmetic, his mind was left to develop itself, and from its own resources to provide amusement and instruction.

When very young he gave evidence of great precocity of mind, and a decided attachment to mathematical pursuits. It is related of him, that, when he was about six years old, a friend, calling on his father, found the boy on the floor, apparently engaged in some childish play. "Why do you," he asked, addressing the parent, "allow this child to idle away his time in this manner? Send him away to the public school." "You may find, sir," the father replied, "that you are mistaken: before you blame me, examine attentively what my son is about." It was, indeed, a sight worthy of attentive examination—a little child, six years of age, attempting to draw and demonstrate a problem from Euclid.

Mr. Watt, perceiving that his son exhibited evidences of unusual talent, and being unable to place him under the restraint of a course of education in a public school, in consequence of his delicate health, permitted him to follow his own inclination, rather directing his energies than selecting his pursuits. Perceiving his attachment

to mechanical studies, and skill in construction, his father purchased for him a small collection of tools, in the use of which he soon became exceedingly expert. His first efforts were displayed in taking to pieces and putting together his toys, which operation he also appears to have repeated with those belonging to his friends. Having made himself master of their construction, he undertook the more serious work of making an electrical machine, in which he was equally successful. In this way he spent, amusing himself and his young friends, many hours of bodily debility and pain. But even in childhood every thing he undertook was made a matter of study and deep investigation. With a clear and perhaps rapid perception, a strong and retentive memory, and, above all, an industry that never flagged, he added daily to his store of information, seldom appropriating any knowledge which he had not thoroughly examined.

His thoughtful and apparently listless habits were not viewed as evidence of genius by all his friends. It is related of him that, on one occasion, when visiting Mrs. Muirhead, his aunt, she reproved him for his absence of mind and apparent indolence. "James Watt," she said, "I never saw such an idle boy: take a book, or employ yourself usefully: for the last hour you have not spoken a word: you have done nothing but take off the lid of that kettle and put it on again, holding now a cup and now a spoon over the steam, watching how it rises from the spout, and catching and connecting the drops it falls

into. Are you not ashamed of spending your time in this way?" Was he who, in after years, became the Hercules of modern times, then studying the powers of that mighty force which he taught to do the bidding and execute the designs of mankind?

From the desultory course of his education, Watt, following the bent of his inclination, pursued with great energy the study of natural and physical science. Experimental philosophy and chemistry were his pursuits at home, botany and mineralogy abroad; nor is it strange that a mind so observant and contemplative should have been drawn with great energy to the latter sciences on the banks of the Clyde and the mountainous shores of Loch Lomond. His bodily weakness and infirmities of constitution led him, naturally enough, to the study of anatomy, surgery, and medicine. With all these sciences he was tolerably familiar before he had reached manhood, and we are not much surprised by the fact. But that he should have been a collector of old ballads, and possessed the inventive faculty of the poet in a high degree, displays him as the possessor of a prodigality of intellectual powers rarely united in the same individual. "He was not fourteen," says Mrs. Marion Campbell, his cousin, and playfellow in childhood, "when his mother brought him to Glasgow to visit a friend of hers: his brother John accompanied him. On Mrs. Watt's return to Glasgow, some weeks after, her friend said: 'You must take your son James home: I cannot stand the degree of excitement he keeps

me in: I am worn out for want of sleep. Every evening, before ten o'clock, our usual hour of retiring to rest, he contrives to engage me in conversation, then begins some striking tale, and, whether humorous or pathetic, the interest is so overpowering, that the family all listen to him with breathless attention, and hour after hour strikes unheeded.' "

He was nineteen years of age before he selected a profession. His brother being engaged in his father's business, he was allowed full liberty of choice; but although he had the advantage, seldom enjoyed, of a comparatively mature judgment before the necessity of selection was forced on him, the variety of his acquirements, and his almost equal adaptation to any intellectual pursuit, made that selection difficult. It was, however, at last determined that he should, under the recommendation of Dr. Dick, professor of natural philosophy at Glasgow, proceed to London, and article himself for three years to Mr. John Morgan, a mathematical instrument maker in Finch Lane, Cornhill. From some cause, it may have been his ill-health, this term was not completed: within a year the indentures were cancelled, and he returned to Glasgow, with the intention of carrying on the trade he had chosen in that city. Here, however, he was met by a difficulty he had not foreseen. The corporation of trades refused to allow him to open a workshop, as he had not served the necessary term of apprenticeship. He was in their estimation an intruder, and all the efforts made to reverse their judgment failed to

shake the fixed determination not to admit a novice. Under these circumstances, the professors of the college, by many of whom the young man was highly esteemed, offered him three rooms within their own walls, and elected him mathematical and philosophical instrument maker to the university. This situation he filled with honor as well as credit. Among his patrons, those who had rescued him from the rigor of corporation laws, were Adam Smith, the well-known author of the "Wealth of Nations;" Black, the professor of chemistry and discoverer of latent heat; and Robert Simson, the translator of Euclid's Elements. There must have been high moral as well as varied and profound intellectual qualities in James Watt, to have made these men, who esteemed him in the first instance only as a clever workman, seek eventually his company and confidence as a friend. No situation could have been more trying to a young man who was almost entirely self-taught. Every man soon finds his level within the walls of a college, and, although merit meets its reward, pretence and imposture receive no mercy. A better proof of Mr. Watt's acquirements and genius cannot be given, than the fact that his workshop was the favorite resort of all the great men who at that time adorned the university of Glasgow, each one drawn there to enjoy his conversation, and to listen to his enlarged view of every subject introduced to his notice. But it would be hard to say whether he was more respected by the professors or loved by the students. Dr. Robison, then a

pupil in the college, well-known afterwards as a contributor to the Encyclopædia Britannica, and author of an admirable Treatise on Mechanics, formed at that time a friendship with him, which through life was never disturbed. He was introduced to Mr. Watt, he informs us, by Drs. Simson, Dick, and Moor, gentlemen eminent for their mathematical knowledge. He saw a workman, and expected no more, but was surprised to find a philosopher, as young as himself, and always ready to instruct him.

"When I was as yet a young student, I had the vanity to think myself a pretty good proficient in my favorite studies of mathematical and mechanical philosophy, and on being introduced to Watt, was rather mortified at finding him so much my superior.

"Whenever any puzzle came in the way of any of us, we went to Mr. Watt. He needed only to be prompted: every thing became to him the beginning of a new and serious study, and we knew that he would not quit it till he had either discovered its insignificancy, or had made something of it.

"On one occasion, the solution of a problem seemed to require the perusal of Leupold's '*Theatrum Machinarum,*' and Watt forthwith learned German. At another time, and for a similar reason, he made himself master of Italian. When to the superiority of knowledge which every man confesses in his own line, is added the naïve simplicity and candor of Mr. Watt's character, it is no wonder that the attachment of his

acquaintances was strong. I have seen something of the world, and am obliged to say, that I never saw such another instance of general and cordial attachment to a person whom all acknowledged to be the superior. But the superiority was concealed under the most amiable candor, and liberal allowance of merit to every man. Mr. Watt was the first to ascribe to the ingenuity of a friend things which were often nothing but his own surmises followed out and embodied by another. I am well entitled to say this, and have often experienced it in my own case."

No better proof of the energy and perseverance with which Mr. Watt pursued all his studies can be given than the success with which he constructed an organ. A natural infirmity denied him the appreciation of sounds—he could not, it is said, distinguish one note from another. That in the construction of the instrument he should have made many mechanical improvements might be expected, but it is really astonishing that its harmonic qualities were improved, and that, by the phenomena of the beats of imperfect consonances, he found out the temperament assigned by a master of art.

CHAPTER IV.

WATT'S EARLY EXPERIMENTS UPON STEAM AND THE STEAM-ENGINE.

We have now arrived at the period when the attention of Watt was first directed to the serious study of steam and the steam-engine. Among the apparatus in the University of Glasgow intended for the illustration of the lectures, there was a model of Newcomen's atmospheric engine. Many efforts had been made to work it, but without success; and it was at last sent by Dr. Anderson, professor of natural philosophy, and the founder of the Andersonian Institution, to Watt for repair. Upon what small and apparently insignificant causes do great events hinge! Little could the person who sent the machine in question have foreseen that, in giving the order for its transmission to James Watt, he was making the first step towards the development of a series of events that were to revolutionize the commerce of the world.

The necessary alterations were made in the model, and when it was returned to its owner, it worked satisfactorily. But, in executing the repairs, the young philosopher's attention was

necessarily drawn to the structure of the engine, and the relative proportions of its parts. Many inquiries were suggested, and Watt was not the man to leave them unanswered. The hours of business he punctiliously employed in his avocations: his experiments were commenced when the workshop was closed. One subject followed another—the termination of one inquiry was but the commencement of a new one—and in each he provided himself with data upon which his inventive skill might be safely employed. He determined, as M. Arago states, the increased volume of water when it passes from the liquid state to that of vapor—the quantity of water which a given weight of coal can convert into steam—the quantity in weight of steam expended at each stroke by a Newcomen's engine of given dimensions—the quantity of cold water which must be injected into the cylinder in order to give the downward stroke of the piston a certain specified force—and, lastly, the elasticity of steam at different temperatures. Although we cannot follow with minuteness the experiments he made, it is necessary that the results should be known, not only to appreciate his labors, but to understand the value of the invention to which they led him. In doing this, his own descriptions may sometimes be employed, which are the more valuable from the scantiness of his written contributions to science.

Mr. Watt wrote but little for the press, but was happily induced by Dr. Brewster to revise a work on the steam-engine, written by his deceased

and much-loved friend, Dr. Robison. Of the notes he added to this work, we shall avail ourselves as far as possible; for not only are the details and results of experiments best described by those who made them, but the respect and honor universally entertained for the memory of this great man give a more than ordinary value to the few words he has left us. His thoughts, happily for mankind, were chiefly embodied in inflexible iron, which he, as it were, animated with a living force. The thoughts of Watt may be read wherever the steam-engine is at work, and all that words can do is to record their history, and to teach the ignorant how they may be deciphered.

Several attempts had been made, before Mr. Watt came to the study of steam, to determine the increased volume of water when converted into vapor by heat. Sir Samuel Morland, it will be remembered, had approximated to the truth, and others had pursued the same inquiries; but with the results of the later experiments, which were probably those alone with which he was acquainted, Watt was dissatisfied. "It being evident," he says, "that there was a great error in Dr. Desagulier's calculation of Mr. Beighton's experiments on the bulk of steam, a Florence flask, capable of containing about a pound of water, had about one ounce of distilled water put into it: a glass tube was fitted into its mouth, and the joining made tight by lapping that part of the tube with pack-thread, covered with glaziers' putty. When the flask was set upright, the tube

reached down near to the surface of the water, and in that position the whole was placed in a tin reflecting oven before a fire until the water was wholly evaporated, which happened in about an hour: it might have been done sooner, had I not wished the heat not much to exceed that of boiling water. As the air in the flask was heavier than the steam, the latter ascended to the top, and expelled the air through the tube. When the water was all evaporated, the oven and flask were removed from the fire, and a blast of cold air was directed against one side of the flask, to collect the condensed steam in one place. When all was cold, the tube was removed, the flask and its contents were weighed with care; and the flask being made hot, was dried by blowing into it by bellows, and when weighed again was found to have lost rather more than four grains, estimated at four grains and one-eighth. When the flask was filled with water, it was found to contain about seventeen ounces and one-eighth avoirdupois of that fluid, which gave about one thousand eight hundred for the expansion of water converted into steam of the heat of boiling water. This experiment was repeated, with nearly the same result, and, in order to ascertain whether the flask had been wholly filled with steam, a similar quantity of water was for a third time evaporated; and while the flask was still cold, it was placed inverted with its mouth (contraved by the tube) immersed in a vessel of water, which it sucked in as it cooled, until in the temperature of the

atmosphere it was filled to within half an ounce measure of water."

The process here adopted was a very simple, and yet ingenious one. Watt's idea was, that if he could ascertain the difference of weight between a vessel full of water, and the same vessel full of steam, he could determine the increase of volume. He first filled a flask with steam, and carefully weighed it, then with water, and weighed it again. Having ascertained the weight of the flask itself, he was brought by a simple calculation to the conclusion that water was eighteen hundred times heavier than steam, or, in other words, that one eighteen-hundredth part of the water required to fill the flask would fill it when converted into vapor—a conclusion which nearly coincided with the result of Morland's experiments.

The quantity of coal required to convert a certain volume of water into steam is one of great commercial importance; but as the result depends greatly upon the application and combustion of the fuel, and as the question is not immediately connected with our present inquiry, it will be sufficient to state that two ounces of coal will evaporate a pint of water, and produce, according to Watt's estimate, two hundred and twenty-five gallons of steam.

Another question, suggested by Newcomen's engine, was the quantity of cold water required to condense steam. To determine this, Watt connected a boiler, in which he could generate steam, with a glass jar containing cold water at a tem-

perature of 52°. When the steam was raised, it passed through the connecting tube, and was condensed by the cold liquid, and this continued to be the result until the water, by the heat it thus received, began to boil. After the experiment was completed, he found that the quantity of water was increased in the proportion of nearly six to seven; from which he deduced that six ounces of water, at a temperature of 52°, was required to condense one ounce of steam.

In the present day, it is well known to every well-educated person, that vapors are produced from liquids by the reception among their particles of a certain quantity of heat, which gives no sensible proof of its presence. This fact was discovered by Dr. Black, at the time Mr. Watt was working for the university, and was one of the most important scientific discoveries of that age. He called the heat thus employed in the formation of a vapor, latent, because, although it gave no increase of temperature to the vapor, it must be parted with, and become sensible, before the elastic fluid can again take the liquid state. Thus, in the experiment just mentioned, six ounces of water at 52° were raised to the boiling-point of 212° by one ounce of water in the condition of steam. Now, as the steam itself was only at the temperature of 212°, it is impossible that its sensible heat could have raised the entire bulk of the liquid to the same point—the effect can only be accounted for by the presence of latent heat in the vapor, given up during condensation. It was naturally enough supposed that this most im-

portant fact was obtained by Mr. Watt from Dr. Black, the undoubted discoverer; but it appears from the experiment just described, and from his own statement, that he had some knowledge of this important scientific truth, although he did not clearly perceive its theoretical value.

With such information as we have now gained, let us return to Mr. Watt's workshop. The model of Newcomen's engine, sent to him by Dr. Anderson for repair, had a brass cylinder, two inches in diameter, with a stroke of six inches. The boiler-room was apparently ample, being larger in proportion to the engine than was considered necessary; yet, with what ought to have been an abundance of steam, the engine could not be kept at work. Watt was consequently compelled to reduce the load upon the piston by diminishing the quantity of water to be raised by the pump. The loss of power in the engine he attributed in part to the smallness of the cylinder, but chiefly to the material of which it was constructed. Brass was known to be a better conductor of heat than iron, and for that, as well as other reasons, it was a less suitable metal. In the model, the cylinder became so hot when the steam was admitted that it could not be touched. This was an advantage in raising the piston, but, on the other hand, it increased the difficulty of cooling the cylinder before a vacuum could be produced for the descent. It therefore seemed desirable that some worse conductor of heat should be used, and a greatly improved action was expected from the choice of such a substance.

Mr. Watt's first attempt to improve the steam-engine was the construction of a cylinder of wood; and with this he made many experiments. He found, as he expected, that the engine worked with a less consumption of steam, and that the condensation did not require so large an injection of cold water. But the piston did not descend with the force he anticipated, or according to what was due from the pressure of the atmosphere. This gave him reason to suspect that the vacuum under the piston was not perfect, and the truth soon broke upon his mind. Supposing the ejected water, after the condensation of the steam, to produce a vapor of a low temperature, there was a sufficient reason why the descent of the piston was not completed with the force expected from the known weight of the atmosphere. To ascertain the temperatures at which water boils under different atmospheric pressures was not then so easy as it is now, and Watt could think of no method by which the information could be obtained. At a former period, he had determined, by Papin's digester, the temperatures at which water boils under pressures greater than the atmosphere. From these results he calculated what the temperature might be with a less pressure, supposing the same rule to apply in both cases; and for this purpose represented the high temperatures and their corresponding pressures on a geometrical curve, and by an ingenious process, which cannot be made clear without a mathematical demonstration, deduced a proportionate fall for a diminished temperature of the same amount.

The results he obtained were only approximations to the truth, but they convinced him that a vapor of low temperature did exist in the cylinder, and consequently that a much larger injection of water than had been usually thought necessary was required. We say a vapor of low temperature, for it must be borne in mind that the temperature of the steam is always the same as that of the water from which it is produced.

But the inquiries of this ingenious man did not terminate here: his character was as fully displayed in his investigation of Newcomen's engine as in the invention and improvement of his own. He discovered that a much larger quantity of steam was consumed in working the former engine than was necessary for the mere filling of the cylinder for the upward strokes. This waste of steam, which was of course equivalent to a waste of fuel, was considerable, and required to be prevented if possible. But it soon became apparent that the waste was incidental to the construction, and as necessary for the working of the machine as the steam which filled the cylinder. For the production of the vacuum in Newcomen's model, it was essential that sufficient water should be injected, not only to condense the steam, but to cool the cylinder; so, on the other hand, it was necessary that a sufficient quantity of steam should be supplied to heat the cylinder as well as to fill it. When the steam was first introduced, it was condensed by contact with the surface of the cold metal, and until the cylinder, through its entire mass, was raised to the

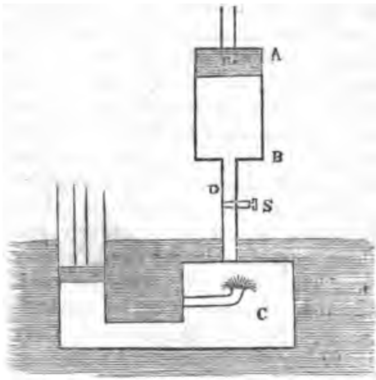
temperature of the steam, that is, the boiling-point of water, a volume of steam, with the necessary expansive power, could not remain actively in force under the piston.

By the experiments already described, resulting from an investigation of Newcomen's engine, it became quite apparent to Watt that there was a great waste of steam, from the necessity of raising the temperature of the cylinder for each upward stroke, and that the mechanical force obtained was not equal to that which was lost. But the necessity of cooling the cylinder, that the atmospheric pressure might give the downward motion, and of heating it before the expansive power of the steam could produce the upward, proved that the waste could not be avoided, unless a vacuum could be obtained by some other means. There appeared, therefore, to be an inherent defect in the atmospheric engine, which had not even been suspected by its inventor, and but little hope was entertained that it could, by any stretch of ingenuity, be corrected.

With his mind earnestly directed to the subject, under a consciousness of its importance, the idea of a condensation of steam in a separate vessel occurred to Mr. Watt in the year 1765, and the details of an engine constructed upon this principle, he said, rushed into his mind, in succession, so rapidly, that in the course of one day his design was sufficiently perfect to admit of his commencing those arrangements necessary to test it by experiment. The value of this happy thought, or, we should, perhaps, rather say, inven-

tion, the reader can at once appreciate from the facts already recorded. The condensation in a separate vessel removed at once the necessity of cooling the cylinder, and, while it prevented the waste of steam, secured a much more perfect vacuum than could be obtained in Newcomen's engine. The instant a communication was opened between the cylinder (when filled with steam after it had lifted the piston) and the condenser, the steam rushes into the vacuum, and means being taken to keep the vessel and the water it contains at a low temperature, it is condensed as it enters, and a comparatively perfect vacuum immediately produced. In the adoption of this plan, it became in fact important to retain the heat of the cylinder, as giving an increased expansive force to the vapor.

That this happy suggestion of Watt's fertile mind—this parent of those wonderful contrivances by which he brought his engine into an effective working condition—may be understood, we must direct the attention of the reader to the following diagram:—Let A B be the cylinder of a steam-engine, and P the piston, with its rod attached: D is a tube, furnished with a stop-cock, S, opening at one end into the bottom of the cylinder, and at the other into a vessel, C, which we will call the condenser. When the piston is raised to the top of the cylinder, as represented in the drawing, the space below it is filled with steam. At this time, let the stop-cock, S, be turned, and a communication be opened with the vacuum in the condenser, in which a jet of water



is supposed to be playing. From the nature of elastic fluids, it follows that the steam, by its expansive power, rushes out of the cylinder into the empty space, to establish an equality of density; but the instant it enters the cold vessel it is condensed, a vacuum is produced, and the piston descends under the unresisted pressure of the atmosphere. Let the stop-cock be now closed, and a connection again opened with the boiler. As the cylinder has not been cooled by the injection of cold water, the steam immediately acts on the piston and drives it upward, the expansive force being rather increased at each successive admission, by the higher temperature of the metal, than diminished, as in Newcomen's engine, by the necessity of raising it to the temperature at which it ceases to be a condensing surface.

But it is apparent that the condenser itself must in time be heated by the steam it condenses, and become unfit for its work. To prevent this result, Watt adopted two contrivances, admirably adapted to secure a permanently low temperature. The condenser was so fixed as to be entirely surrounded by water, as represented in the diagram, and a jet of cold water was kept constantly playing into it. But a method of discharging the water thus introduced (the temperature of which would be constantly increasing by the heat imparted in the condensation of the steam) was also required. This he supplied by the application of a pump to be worked by the engine itself. Nor was this the only duty it performed. Water always contains a greater or less quantity of atmospheric air, and it was impossible to introduce one into the condenser without the other. Being brought with the water into contact with the hot steam, it would expand, and entering the cylinder prevent the formation of a vacuum, for being a permanent gas it could not be condensed like the vapor, steam. In consequence of the usefulness of the pump in preventing the accumulation of air, it is generally known by engineers under the name of the air-pump, although this is only a part of the important office it performs.

No sooner had Watt proved the value of these inventions than another was suggested to his mind, which dispensed with atmosperic pressure, and converted his contrivance into a steam-engine, every motion being produced by that vapor. In

the construction of Newcomen's engine, it had been customary to cover the piston with water, in order to make it steam-tight. Watt perceived how disadvantageous this would be to his contrivance, for not only would the passage of any portion of the fluid into the lower part of the cylinder cause an immediate formation of steam, but air also would be introduced, interfering in a still greater degree with the production of a vacuum and the working of the engine, to say nothing of the effect of the water in cooling the cylinder in its passage up and down with the piston. The consideration of this subject led him to inquire as to the possibility of entirely surrounding the cylinder with steam, so that the downward stroke might be produced by the expansive force of that fluid instead of the pressure of the atmosphere. This design he carried into practice, and surrounded the cylinder with a casing, now called a jacket, filling the interval between them with steam from the boiler. The top of the casing fitted closely, and an aperture was accurately bored in the centre, through which the piston-rod moved steam and air-tight. The downward stroke being now made by steam, the force was always under control, being increased or diminished at pleasure: the exterior as well as the interior of the cylinder was kept at a sufficient temperature, and every provision was made against the intrusion of atmospheric air into working spaces.

We need not point out the evidences of deep

thought, penetration, discrimination, and industry displayed by Watt in the pursuit of the object he had resolved to attain, and in describing his inventions we have sufficiently exhibited their importance. Wanting the capital necessary for the introduction of his improvements, he fixed his models in a place called Delft House, in Glasgow, and invited the attention of those whom he thought best able to judge their merit or appreciate their importance. All admired, but none offered assistance. Nor was this strange. Little was it to be expected that an obscure mechanic, not thirty years of age, whose whole life seemed to have been spent either in scientific reveries or in the construction of philosophical toys, was destined to produce a machine which should give an impetus to industry, advance the conditions of society, open a communication between nations the most distant, demand from legislators a revision of laws, and from all men, kings and people, submission, praise, and gratitude. Nor did the indifference with which his discoveries were received greatly affect him: he was willing to wait, if that were necessary, but he could no longer continue his former employment.

Having closed his workshop at Glasgow, Mr. Watt devoted himself to the duties of a civil engineer. For three years, he was actively engaged in this pursuit, and was intrusted with several large and important enterprises. Among other works, he made a plan for a canal to convey coal from the Monkland collieries to Glasgow, which

he executed. He also prepared a survey for a navigable canal through the isthmus of Crinan, a work afterwards executed by the elder Rennie. He also made investigations of, and reported improvements for, the harbors of Ayr, Glasgow, and Greenock. To these labors may be added the deepening of the river Clyde, the rendering navigable the rivers Forth and Devon, and the water of Leven; the planning of a canal from Macrihanish Bay to Campbeltown, and of another between the Grand Canal and the Harbor of Borrowstounness; the building of Hamilton and Rutherglen bridges, and the surveys and plans for the Caledonian Canal.

During this long period his engine was in abeyance, and he waited hoping for the time when he might secure its adoption. In the year 1768, he was employed as a civil engineer by Dr. Roebuck, the proprietor of the Carron Iron Works. To him he mentioned the improvements he had made in the atmospheric engine. A patent and partnership was suggested by Roebuck, and Watt consented to make over to his employer a two-third share of the profits to be derived from the invention, in consideration of the advantages he was likely to receive from his large capital and extensive connection. A patent was accordingly taken out, and an experimental engine was made, which more than fulfilled the anticipations of the inventor. Difficulties as they arose were one after another met, and every thing seemed to promise an unexampled success, when Dr. Roebuck found

himself involved in pecuniary difficulties, in consequence of the failure of his undertaking in the Borrowstounness coal and iron works, and was unable to supply the necessary funds for the prosecution of the design.

CHAPTER V.

PROCEEDINGS AT THE SOHO WORKS.

However disappointed Mr. Watt may have been by the failure of his hopes through the inability of Dr. Roebuck to carry on the projected manufacture of his engines, he was not long left without the assistance he required. His inventions had already become known to many intelligent men engaged in manufactures, and, among others, to Mr. Matthew Bolton, of Soho Works, near Birmingham. This gentleman was at that time carrying on one of the largest and most successful metal trades in England, and was alike distinguished for his business habits and commercial enterprise. In the moment of Watt's perplexity, Bolton made an offer for the purchase of Dr. Roebuck's share in the patents: terms were made, and the agreement was completed. In the early part of the year 1774, Mr. Watt removed to Soho, where a portion of the manufactory was placed under his entire control, for the erection of a foundry, and all other shops and machinery necessary for carrying out his inventions upon the largest scale, and in the most perfect manner.

On a review of the expenses already incurred, and a calculation of those which had to be borne before the engine could be perfected, and the works made suitable for the manufacture, it became evident that an extension of the patent-right should if possible be obtained. The patent had been granted in 1769 for a period of fourteen years, and would therefore terminate in 1783, so that the remaining term was too short a period to give security for the return of the large capital to be invested in the undertaking. In consideration of the risk, and of the labor and skill yet to be expended, an application was made to parliament for a lengthened period of protection, and, in 1775, an act was passed extending the patent to the year 1800.

Those who know any thing of the construction of machinery are well aware that, after the most careful and minute examination of a new design, alterations and improvements are frequently suggested in the progress of manufacture; and they can easily understand how numerous and varied these must have been in the early history of the steam-engine. The comparatively low state of mechanical art, the necessity of proving every invention and application, and of designing new tools for the construction or performance of the work required, were not the only impediments Mr. Watt had to overcome. He had the still more difficult task of teaching others how to execute what he designed. He was not, like the engineer of the present day, surrounded by men educated to their trade, neither asking nor

needing more than a drawing of what is required. He introduced a new engine, and with it a new style of work: precision and minute accuracy were indispensable, and prejudices were to be overcome; confidence, too, was to be inspired—that strange feeling of reliance on a superior mind which must exist between a superintendent and his workmen to secure respect, obedience, and promptitude. To all this the great mechanist was equal, though his health suffered from his exertions. "I have been," he says, in a letter to Smeaton, dated April, 1766, "tormented with exceedingly bad health, resulting from the operation of an anxious mind, the natural consequence of staking every thing upon the cast of a die; for in that light I look upon every project which has not received the sanction of repeated success."

The engine first constructed at Soho, afterwards known as the single-action engine, was in principle the same as that already described, but much improved in its details. Every experiment made a demand for greater accuracy. The mechanist was now for the first time bringing under control one of the most subtle agencies of nature. Previous mechanicians had been able to forge and form hard inflexible bodies to their purpose: they had commanded and directed the flowing water, and from its motion obtained forces acting in power and direction according to their will: the air which came and went without their control, they stopped in its course by sails, and thus carried vessels over the ocean. Still, the air owed

the mechanist no obedience, and gave him none; nor could steam, a force as indocile, be brought into subjection by such rude contrivances and rough workmanship as had been applied for the control of grosser bodies.

The improvement effected by Mr. Watt in the construction of the engine, without reference to the alteration of principle and design, is shown by a comparison of the cylinder, piston, and rod of Newcomen's engine with those of his own.' In the former, the cylinders were bored with little regard to accuracy, and the rough rod was attached to the piston by two or four stays or brackets, a mode of construction by which it was impossible correct action could be obtained. In Mr. Watt's engine, the piston-rod was accurately turned and finished, with a bright surface, and it moved steam-tight up and down through the cylinder cover in a contrivance called the stuffing-box, which is a metallic cup, lined with hemp or tow saturated with oil or tallow. The cover was fixed to the cylinder so accurately as to prevent the passage of air inwards and of steam outwards, and the piston and its rod were so attached that the motion from the top to the bottom was perfectly perpendicular. But all these precautions could not secure the accomplishment of Watt's designs while the boring of the cylinder remained irregular. To correct this evil, as far as possible, he made the piston so that it might be packed with hemp; but the necessity of improvement is always soon met by the discovery of the thing sought for. In a letter to Smeaton, from which

we have already quoted, he says, "Mr. Wilkinson has improved the art of boring cylinders, so that I promise, upon a seventy-two inch cylinder, being not further distant from absolute truth than in the thickness of a thin sixpence in the worst part."

After all had been done that ingenuity could devise and industry accomplish, Bolton and Watt had still to wait for success. Finding it impossible to get any one to manufacture the parts requiring precision with the necessary accuracy, they obtained machinery of their own, and it continued to increase from time to time until they were able to construct every part of the engine in their works. But they could not command sales. They offered many advantages; but prejudice was stronger than the hope of gain. They looked to the mines of Cornwall, hoping to find customers there; but the proprietors, though dissatisfied with the pumping engines they employed, were unwilling to try another, so often had they believed promises of assistance, and been deceived. At Soho, two inducements were offered for the adoption of Watt's engine—a saving in fuel, and a cheap engine. "I can assure you," says Mr. Bolton, "that our small engine at Soho is capable of raising 500,000 cubic feet of water one foot high, with every one hundred and twelve pounds of coal." This was an effective work, far beyond the power of any engine at that time in Cornwall; but in the present day the average work of a Cornish engine may be calculated at more than four times Mr. Bolton's estimate.

When applied to by the Carron Company for the terms on which he would provide such an engine as they required, Mr. Bolton offered it at cost price, upon condition of receiving yearly one-third of the amount saved in fuel, compared with the engine they had then at work, or any other which they might select in Scotland.

The growing necessities of the miner as he sank his shafts deeper into the earth, and the patient perseverance of Bolton and Watt, who availed themselves of every opportunity of exhibiting the power of their engine, at last created confidence, and the superiority of their contrivance being once acknowledged, all difficulties were removed. The invention was generally adopted, and the prospect of a reward for their labor and industry came nearer, and was more cheering. Watt, relieved from the anxiety he had for years felt, now turned his attention to the application of his engine to the driving of machinery. To understand the value of his labors in this new adaptation of steam-power, which, although then thought to be of secondary, is now felt to be of primary importance, it will be necessary to understand also the state of the manufactories in England previous to the introduction of the steam-engine.

When Savery's engine was invented, all mills (a name given to large workshops where motive-power is used, whether from water or steam) were built by the sides of rivers and streams, and the mechanical force required was obtained from the revolution of water-wheels. Floods and

droughts interfered with the regular working of these power-mills, and the manufacturer was sometimes inconvenienced; but orders were not so urgent, and competition was not so common, as to make this of very great importance. About the middle of the eighteenth century, however, a great change came over the manufacturing interests of England. There was a large demand for goods, and an increased number of capitalists sought means to supply it: time was raised in value, and men, perhaps, were seized more violently with the desire to be rich. Under these circumstances, the loss of a few days, and sometimes of a few weeks, was severely felt, and the anxious manufacturer began to inquire whether any thing could be done to remedy such ruinous delays. In 1752, Mr. Champion, of Bristol, the proprietor of extensive brass-works, fixed an atmospheric engine upon his premises to drive a number of wheels, and this, we believe, was the first introduction of a steam-engine into a manufactory.

It was about this time that Smeaton was engaged in the study of water and wind-mills. The success attending his inquiries did almost as much for the improvement of these machines, as Watt's inventions effected for the steam-engine—a circumstance which for a time was an impediment to the introduction of the latter in its new form. To prevent the inconvenience arising from the stoppage of works in times of drought, Smeaton provided horse machinery, which could be applied to raise the water necessary for driving the wheels.

But animal power could not long continue in use, being both inefficient and expensive: it was resorted to with reluctance, and abandoned on the first opportunity. In the Hartley colliery, in Northumberland, an attempt was made, in 1762, to obtain a rotatory motion from a steam-engine, and by means of it to lift the coal from the pit. The invention was unsuccessful; but it was eventually employed to raise water for driving a wheel and machinery, by which the object in view was attained. In Colebrook Dale iron-works, also steam-engines were erected to raise water for wheels during dry seasons. In these large works, likewise, a considerable power was also required to secure a constant draught of air by the rotation of fans, in order to keep the furnaces at a proper temperature; and in this instance, likewise, the new application was successful. Thus did the great contrivance, destined in time to supersede all other sources of motive-force, slowly obtain a place for exhibiting its powers, although used only in an humble capacity as a drawer of water.

To those who had most carefully studied the steam-engine, it seemed impossible that it should long remain confined to the production of a vertical motion; and those who knew least of its capabilities, witnessing its power, regretted that it was only useful for pumping. In 1777, Mr. John Stewart proposed a method of obtaining a continuous rotatory motion from the steam-engine, and presented an explanatory paper to the Royal Society. He proposed to accomplish his object

by the use of two endless chains, passing over pulleys, and the application of a fly-wheel. His scheme was an inefficient one, but it is worthy of notice that he incidentally alludes to the possibility of obtaining a rotatory motion by means of a crank, (the mode now generally adopted,) which, he concludes, however, could not be applied, because, as the motion of the engine depends on the force of the steam, its length cannot be ascertained, and on the first variation in the motion of the engine it would turn the latter back, or break it to pieces. Mr. Stewart's paper was referred by the Royal Society to Mr. Smeaton, who, curiously enough, not only agreed with this absurd objection to the use of the crank, but also condemned the adoption of a fly-wheel, which he admitted would be of advantage in regulating the motion, but to be effective would require to be so large that the engine itself could not keep it under control. It is more than strange that two engineers, both eminent in their profession, and one distinguished by the extent of his practical knowledge, and the general accuracy of his opinions, should have fallen into such errors. It cannot be unknown to any of our readers acquainted with the elements of the subject, that the application of the crank is an indispensable adjunct to the steam-engine, and in all instances where it is used for the motion of machinery the fly-wheel is adopted.

Mr. Wasbrough, an engineer at Bristol, took out a patent in 1779 for the production of circular motion from a steam-engine by ratchet-wheels,

the motion being regulated by a fly-wheel. This invention was employed by the patentee in several engines, and among others in one erected at Birmingham.

It will now be asked what Mr. Watt had been doing while these inventions were forcing themselves upon public attention. If we turn again to his single-action machine, two difficulties in the way of obtaining rotatory motion will be detected. The first and most evident is, that the motion of the engine was rectilinear. The second difficulty was, that the force of the engine was intermitting, and for a circular motion it was necessary that it should be constant and uniform. The work of his engine was confined to the descending motion of the piston—during the up stroke of the piston it was suspended. It was necessary, therefore, in order to make it applicable to a rotatory movement, either to change the principle of operation, or to devise some method of sustaining the motion of a revolving shaft while the power of the engine was suspended. Watt knew all this, and his mind had not been inactive. While others were apparently obtaining the advantage of patents, and superseding him, he possessed what they sought. The history he has given of the method by which he succeeded in obtaining a rotatory motion from the steam-engine, is so curious, and will be read with so much interest, that it must be quoted in full: "I had very early turned my mind to the producing continued motions round an axis, and it will be seen by reference to my first specification, in 1769,

that I there described a steam wheel, moved by the force of steam acting in a circular channel against a valve on one side, and against a column of mercury, or some other fluid metal, on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly, but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines, which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning-lathe, (an invention of great merit, of which the humble inventor, and even his era, are unknown.) But as the rotative motion is produced in that machine only by the impulse given to the crank in the descent of the foot, and behooves to be continued in its ascent by the momentum of the wheel, which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston, I proposed to employ two engines, acting upon two cranks, fixed on the same axis, at an angle of 120° to one another, and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means

the motion might be rendered nearly equal, and a very light fly would only be required.

"This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 1779, when Mr. Wasbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated, by a workman employed to make the model, to some of the people about Mr. Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam-engines. This fact the said workman confessed, and the engineer who directed the works acknowledged it; but said, nevertheless, that the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time; which might be a fact, as the application to a single crank was sufficiently obvious.

"In these circumstances, I thought it better to endeavor to accomplish the same end by other means than to enter into litigation; and, if successful, by demolishing the patent, to lay the matter open to everybody. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, among which was the sun and planet wheels. This contrivance was applied to

many engines, and possessed the great advantage of giving a double velocity to the fly-wheel; but is, perhaps, more subject to wear, and to be broken under great strains, than a simple crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis: my application of the double engine to these rotative machines rendered the counter-weight unnecessary, and produced a more regular motion."

The idea of using two cylinders and pistons working alternately, which it will be recollected was the mode in which his first engine was made, did not long satisfy Mr. Watt's mind, and further thought convinced him that a single cylinder would accomplish all he desired, if a means could be devised of producing both the upward and downward motion by the expansion of the steam from the boiler. This he succeeded in doing in his double-acting engine, which may justly be considered as the perfection of his inventive power. The mode in which he accomplished his object was by bringing the upper and lower end of the cylinder alternately in connection with the boiler. During the descent of the piston, the upper part of the cylinder received steam, and by its expansion the downward motion was produced, instead of merely by the pressure of the atmosphere as had formerly been the case, the lower part being open to the condenser. For the up stroke, the arrangement was reversed. The lower part of the cylinder received steam, and the upper was exhausted by a union with the condenser. In

both the upward and downward motion, therefore, the pressure of the steam was against a vacuum. For this contrivance Watt obtained a patent in March, 1782. Many changes in mechanical detail were required by this alteration of principle, and at no period was his ingenuity more severely taxed, but his genius triumphantly overcame every difficulty. Since his time, many improvements have been introduced, and the power of the engine has been greatly increased; yet in its general character, and in many of its details, the steam-engine is now essentially what Watt made it. Just as the animal body is constantly changed in its contour, while the anatomical structure retains in maturity the outline distinguishing it in youth, so the varieties in the engine are but different developments of form and condition upon the same elementary structure. But before we proceed to any more minute description of the double-action machine, another important invention must be explained. A valuable and economical change was made in the steam-engine by the adoption of the principle of expansion. As this invention has been sometimes claimed, on the point of priority, for Mr. Hornblower, it is necessary to give some evidence that Mr. Watt had previously used as well as thought of it. In a letter written from Glasgow to Dr. Small, of Birmingham, in May, 1769, he says: "I mentioned to you a method of doubling the effect of the steam, and that tolerably easy, by using the power of steam rushing into a vacuum, at present lost. Open one of the steam valves, and admit

steam until one-fourth of the distance between it and the next valve is filled with steam, then shut the valve, and the steam will continue to expand." In 1776, he applied the principle of expansion to the Soho engine, but took out no patent till the year 1782.

When it is said that an engine works expansively, or upon the principle of expansion, it may not be very readily understood what is meant. All engines work by the expansive power of steam, and it is this property alone that gives a value to the vapor of water as a mechanical force. In the engine already described, the cylinder was filled with steam of the same density, the valve connecting it with the boiler remaining open during the entire stroke of the piston. But it is possible to shut off the steam before the piston comes to the top of the cylinder; when, for example, it has passed through a half or two-thirds of its course. If this be done, the remainder of the stroke must be completed by the expansive power of the steam contained in one-half or two-thirds of the cylinder, assisted by the momentum. The saving this effects in the consumption of steam, and consequently of fuel, is evident; and in practice, as now employed, it is as effective as when the cylinder is completely filled with steam of the same elasticity as that at which it issued from the boiler. In Cornwall, high-pressure steam is always used, four atmospheres, or sixty pounds upon an inch, being common; and there all the engines are made to work expansively, the steam being cut off when the piston has performed

a fourth part of the stroke, the remainder being accomplished by the expansive power of what is then admitted. This is not more an economical mode of employing steam than it is a correct one. If there be a full cylinder of steam of the same expansive power as when first admitted, there is a waste of force, and the momentum of the piston, increasing through the length of the stroke, is at last injuriously expended upon some part of the machinery. When working with low-pressure steam, a term given to it when the pressure does not exceed that of the atmosphere, the principle of expansion is of but small importance; but when high-pressure is used, the advantages are very great.

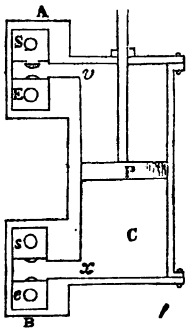
One objection, however, has been made to its adoption, which must be mentioned, although it is now fully met in practice. There is in each stroke a variation in the intensity of the moving power. The moment the supply of steam from the boiler is stopped, the steam in the cylinder begins to increase in volume, and its expansive power decreases in proportion. The motion, for the same reason, also diminishes in velocity, just as it would increase by the removal of a portion of the load. The effect of a diminished resistance, as, for instance, the throwing off the bands, or otherwise disconnecting large machines in mills, is to increase the velocity of the engine; but this is admirably provided for by the governors, as will be hereafter explained. The opposite effect results from shutting off the steam before the stroke is completed—the motion is retarded. But, as it

has been well observed, "this variation in the speed will not disturb the mechanical effect produced by the power, provided the momentum imparted to the moving mass (that is to say, the piston and rod, the pump-piston and rods, the column of water, and the beam) be allowed to expend itself at the end of the stroke."

Hornblower applied the principle of expansion ingeniously, by the adoption of two cylinders worked by the same beam, and obtained a patent for his invention. These cylinders were made of different sizes, the smaller receiving the steam from the boiler, the larger being worked by the same steam expansively. The piston-rods of these two cylinders were attached by chains to arch-heads on the same side of the beam, the distance of the arch-heads from the centre of the beam being in the same proportion as the length of the cylinders. By the adoption of this plan, he hoped to secure a uniform motion; for while in one cylinder the motion is an increasing one, in the other it is decreasing. The power of the engine was equal to that of Mr. Watt's, but did not offer any advantages, or at least none equivalent to the increase of cost.

We may now return to the double-action engine of Watt, which requires some further explanation, although, for obvious reasons, it is neither possible nor desirable that we should enter into any details of construction. To make the principle of the contrivance sufficiently simple to be understood by those least acquainted with machinery, we must introduce a diagram, supposed to be

the section of a cylinder, or the appearance it would have if cut in halves lengthway. C is the cylinder, and P the piston. A and B are called steam-boxes, one the upper and the other the lower, and they respectively communicate by the passages *v* and *x* with the top and bottom of the cylinder. In each box there are two valves, one on each side of the steam passages *v* and *x*. S and *s* are in connection with the boiler, the steam entering them by a pipe (shown in the drawing by a circular disc), and E and *e* are, in like manner, connected with the condenser. Supposing the piston to be at the top of the cylinder, the valve S is opened, and steam is admitted, forcing



the piston downward, and at the same time a communication is formed between the lower part of the cylinder and the condenser, for the discharge of the steam therein contained, by the valve *e*. When the piston is to be forced up-

ward, these valves are closed, and the valve *s* is opened for the admission of steam from the boiler, and E for the condensation of steam in the upper part of the cylinder. To perform what has been here described, a mechanical arrangement is required to open the valves in pairs, the steam valve of one box with the condensing valve of the other. For this many clever inventions have been proposed, but they all admit of arrangement under one of two classes: they are either slide-valves or four-way cocks, and in all instances they are so attached to a working part of the engine, as to require no manual assistance.

The connection between the beam and the piston-rods was made, in the single-action machines by a chain working over an arch-head. This arrangement was evidently inapplicable to the new invention. In the former, the mechanical action required was a pull, for the force of the piston upon the beam was only during its descent. But, in the double-action engine, power was required for the ascent as well as descent, so that a push was necessary as well as a pull, and for this the chain was evidently unfit. Watt's first thought was to attach a rack to the end of the piston-rod, to work in corresponding teeth upon the arch-head. But this plan was quickly rejected, and that beautiful contrivance called the parallel motion was adopted. "I have lately contrived," he says, in a letter to Smeaton, dated 22d October, 1784, "several methods of getting entirely rid of all the chains and circular arches

about the great levers of steam-engines, and, nevertheless, making the piston-rods ascend and descend perpendicularly, without any sliding motions or right-lined guides, merely by combinations of motions about centres; and with this further advantage, that they answer equally well to push upwards or pull downwards, so that this method is applicable to our double engines, which act both in the ascent and descent of their pistons.

"A rotative engine of this species, with the new motion, which is now at work in our manufactory, (but must be sent away very soon,) answers admirably. It has cost much brain work to contrive proper working gear for these double engines, but I have at last done it tolerably well, by means of the circular valves, placed in an inverted position, so as to be opened by the force of the steam, and they are kept shut by the working gear."

There are few mechanical contrivances which so much astonish and delight the observer as Watt's parallel motion, and the mechanist partakes in the pleasure of the uninstructed examiner. "Among the parts composing the steam-engine," says M. Arago, "you have doubtless observed a certain articulated parallelogram. At each ascent and descent of the piston, its angles open and close with the sweetness—I had almost said with the grace—which charms in the gestures of a consummate actor. Follow with your eye alternately the progress of its successive changes, and you will find them subject to the

most curious geometrical conditions. You will see, that of the four angles of the jointed parallelogram, three describe circular arches, but the fourth, which holds the piston-rod, is moved nearly in a straight line. The immense utility of this result strikes mechanicians with even less force than the simplicity of the means by which Watt has attained it." The inventor himself said that when he first saw his contrivance in action, he received from it the same enjoyment as is usually experienced in viewing the successful invention of another person.

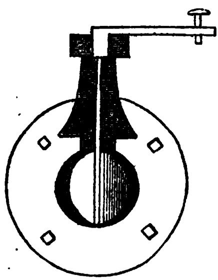
There is yet one other contrivance of this great man which must be explained—the governor; and to make this explanation useful, a few preliminary remarks are required.

The best means of obtaining a rotatory motion, as already observed, is by the use of a crank. But in the revolution of a crank there are two dead points, or, in other words, points where the moving power ceases to impel it. These are at the highest elevation and lowest depression, when on the verge of changing the direction of its motion, which is when the piston is at the top and bottom of the cylinder. If the crank were at these points to come absolutely to rest, the steam would be unable to move the engine; but the momentum acquired by the first stroke, which is made before any great load comes upon it, carries it over these positions. From this cause, however, there will always be an irregularity of motion, and it may happen, when certain valves do not act promptly, and an excessive load is

suddenly put on to the engine, that the crank may be brought to rest on a dead point. To correct this irregularity, Watt placed a heavy metal wheel, called a fly-wheel, upon the shaft. Being put into motion with the shaft, its momentum assists in carrying it over the positions where the steam ceases to act. When the crank is in those positions where the power is most effective upon it, a portion of that power is expended in increasing the velocity of the fly-wheel, and when in those where the power is lost, it is carried forward by the fly-wheel.

When these arrangements have been made in the best and most effective manner, the engine will still be wanting in regularity of motion. If the amount of steam supplied to the cylinder were always the same, there would be a constant increase and decrease of velocity from a perpetual change in the load. In an engineer's shop, for example, all the machines are rarely at work at the same moment—it is but seldom that the lathes, punches, shears, and other tools, are in operation at the same time. Upon the increase of the load which it has to bear, the engine must have a diminished velocity, and when it is greatly lessened or altogether removed, the speed will be undesirably or even dangerously increased. To regulate the speed according to the load, there must be some means of decreasing or increasing the proportion of steam admitted into the cylinder, as the change of load may require. For this purpose Watt fixed in the steam-pipe a valve of peculiar construction, called a throttle-valve. We

have given a section of this contrivance as it appears when fixed in the steam-pipe, and partly open. It consists of a thin circular plate of brass, (iron is not a suitable metal, as it would soon be destroyed by oxidization,) so mounted on an axis that it may either be made to present its edge to the current of steam, and so leave the passage open, entirely close it, or take any intermediate position. For the regulation of this valve, a small



lever was in the first instance provided, so as to enable the engine-driver to adjust at pleasure the quantity of steam admitted to the cylinder. But Watt soon perceived that he could not leave the control of the throttle-valve to the driver, however skilful and vigilant he might be. There is a source of irregularity in the motion of the engine, independent of the load. The elastic force of the steam is liable to rapid change from the slackness or the intensity of the fire, and from many other sources of disturbance, and the engi-

neer, if he perform his duty, finds ample employment in other necessary labors. From these considerations, and, perhaps, from a desire to make the engine self-acting, the idea of leaving the throttle-valve to such precarious attendance was abandoned. A mechanical arrangement being imperative, Watt adopted the best that could be found, and one that will probably remain in use as long as the steam-engine itself.

The governor of a stationary engine is one of the first things that attracts the attention of a stranger in the engine-room; and it is certainly not the less interesting when the principle of its action is investigated. Two balls, which are so connected with the fly-wheel shaft as to partake in all its changes of velocity, are seen to revolve round and round, faster or slower, collapsing or separating, in a strange, and, at first, in a very unaccountable manner. It would scarcely be imagined that the motion of these two balls towards or from each other regulates the admission of steam into the cylinder, and yet such is the fact. They are connected by a series of levers with the throttle-valve: when diverging, they close, when collapsing, they open it. Whatever alteration there may be in the velocity of the fly-wheel shaft, it is, as we have already stated, communicated to the balls. Now, it is generally known that the greater the velocity of any body revolving round a centre, the greater is the centrifugal or centre-flying force, and, therefore, just in proportion to the speed of the fly-wheel shaft will be the distance to which these balls separate. The effect

of this, communicated by a series of levers, is, partially or entirely to close the steam-passage. When the balls are close together, the velocity is small, and the steam-passage is quite open, because the valve presents its edge in the direction of the passage of the steam. As the velocity increases, the valve is turned more and more, until at last it completely covers the opening, and shuts off the further admission of steam into the cylinder. The governor has thus a complete control of the throttle-valve, and every irregularity of speed is immediately corrected by the admission of a greater or less quantity of steam.

In the year 1800, the patent-right granted to Bolton and Watt expired, and the great mechanist then retired from business, leaving the works at Soho to Mr. Bolton, the son of his partner, and his own two sons, James and Gregory. Gregory Watt died four years after of a pulmonary complaint, in the twenty-seventh year of his age—an event deeply afflicting to his father. James Watt continued for some time to carry on the works at Soho, but he also is now dead; and not long since the auctioneer stood among a crowd of curious purchasers in this once busy and prosperous workshop.

CHAPTER VI.

THE DOMESTIC LIFE AND PERSONAL CHARACTER OF JAMES WATT.

A LEARNED and devout man, well known for his Christian charity—that charity which thinketh no evil—was once insidiously tempted by an acquaintance to acquiesce in some injurious reflections upon the private life of a neighbor. "Do you not think he is a bad man?" the defamer inquired. "I do not know—I never lived with him," was the judicious and Christian reply. It would be well if the spirit of this reproof to an uncharitable man did more perfectly control the conversation of mankind. But the invidious and unholy spirit which delights in fault-finding, excusing or exalting itself by an implied comparison with another, is as commonly employed upon the characters of the dead as of the living. Some men are so acrid that they blister all they touch: nothing, after passing through their hands, is left with a tolerably fair and smooth skin: every surface is blotched by their handling. Some fault or failing, some habit of business, some trait of domestic life, offends them, and the man's character is at once condemned to all the tortures of

their excoriating pens. There are salient points in the lives of all men open to the attack of these inquisitors; but they are few and not prominent in the life of James Watt.

The possession of great intellectual qualities, and the attainment of weath and honor, do not guarantee the possession of a serene and peaceful life. Home is frequently the arena of discord or tyrannous oppression, even when the world looks on the man with its most complacent smile. It was not so in the dwelling of James Watt. His disposition was the same in manhood as in youth—quiet, thoughtful, persevering, were the terms which best described his character. The strong decision of his mind gave sometimes a stiff, unbending attitude to his will; but it was never offensively exhibited, and he seldom lost the affability which marked his ordinary conversation.

During his residence within the walls of Glasgow College, Watt can scarcely be said to have commenced his domestic life. In 1764, about the time when he was changing his pursuits from that of a mathematical instrument maker to that of a civil engineer, he married Miss Miller, his cousin. Two sons and two daughters were the offspring of this union. One child of each sex died in infancy. In 1773, while he was engaged with the plans of the Caledonian Canal, his wife also was taken from him. These afflictions were deeply felt, and his mind was brought under the softening influence of domestic grief. It is not for us to intermeddle with the sorrows of a great mind at such an hour, and we would not if we

could attempt to describe what in nature it suffered, what in obedient submission it endured. For some years after the death of his first wife Mr. Watt remained a widower. His second marriage was to Miss Macgregor. This lady survived her husband, and died at an advanced age in the year 1822.

The reputation Mr. Watt had earned in the world by his successful career, and among his friends and acquaintances, by his genius, urbanity, and kind-heartedness, impressed the one with respect, and the other with affectionate admiration. When Watt was no more, rivals forgot their jealousy, and joined with those who had been largely benefited in acknowledging his genius and skill; but while the men of commerce—the representatives of pounds, shillings, and pence—came slowly and deliberately to acknowledge their obligations to James Watt, the men of genius, his personal friends and companions, were in haste to offer their testimonies to his character and talent. To them we may well leave the description of what James Watt was in his domestic life and personal character. The memory of no man was ever so wisely embalmed for perpetuity in the history of his country. Three of the most gifted of his countrymen—Brougham, Scott, and Jeffrey—all possessing traits of character differing from and in some respects greater than his, and yet in some points all his inferiors, joined to do him honor, and to them we may leave the completion of this chapter.

Sir Walter Scott thus describes an interview he

had with the great mechanist, and vividly portrays his character and genius :—

"There were assembled about half a score of our northern lights. Amidst this company stood Mr. Watt, the man whose genius discovered the means of multiplying our national resources to a degree perhaps beyond his own stupendous powers of calculation and combination: bringing the treasures of the abyss to the summit of the earth: giving the feeble arm of man the momentum of an Afrite: commanding manufactures to arise as the rod of the prophet produced water in the desert: affording the means of dispensing with that time and tide which wait for no man, and of sailing without that wind which defied the commands and threats of Xerxes himself. This potent commander of the elements—this abridger of time and space—this magician, whose cloudy machinery has produced a change on the world, the effects of which, extraordinary as they are, perhaps are only now beginning to be felt—was not only the most profound man of science—the most successful combiner of powers and calculator of numbers as adapted to practical purposes—was not only one of the most generally well-informed, but one of the kindest of human beings.

"There he stood, surrounded by the little band I have mentioned of northern literati: men not less tenacious, generally speaking, of their own fame and their own opinions, than the national regiments are supposed to be jealous of the high character which they have won upon service. Methinks I yet see and hear what I shall never

see or hear again. In his eighty-second year, the alert, kind, benevolent old man had his attention alive to every one's question, his information at every one's command.

"His talents and fancy overflowed on every subject. One gentleman was a deep philologist—he talked with him on the origin of the alphabet, as if he had been coeval with Cadmus; another a celebrated critic—you would have said the old man had studied political economy and belles-lettres all his life Of science it is unnecessary to speak—it was his own distinguished walk."

At a meeting convened in 1824 to make provisions for the erection of a monument to Watt, Lord Brougham expressed with great felicity the opinions all present entertained of this great man.

"I had the happiness of knowing Mr. Watt for many years, in the intercourse of private life; and I will take upon me to bear a testimony, in which all who had that gratification I am sure will join, that they who only knew his public merit, prodigious as that was, knew but half his worth. One of the most astonishing circumstances in this truly great man was the versatility of his talents. His accomplishments were so various, the powers of his mind were so vast, and yet of such universal application, that it was hard to say whether we should most admire the extraordinary grasp of his understanding, or the accuracy of nice research with which he could bring it to bear upon the most minute objects of investigation. I forget of whom it was said, that his mind resembled the trunk of an elephant, which

can pick up straws and tear up trees by the roots. Mr. Watt, in some sort, resembled the greatest and most celebrated of his own inventions, of which we are at a loss whether most to wonder at the power of grappling with the mightiest objects, or of handling the most minute; so that, while nothing seems too large for its grasp, nothing seems too small for the delicacy of its touch; which can cleave rocks, and pour forth rivers from the bowels of the earth, and with perfect exactness, though not with greater ease, fashion the head of a pin, or strike the impress of some curious die. Now those who knew Mr. Watt had to contemplate a man whose genius could create such an engine and indulge in the most abstruse speculations of philosophy, and could at once pass from the most sublime researches of geology and physical astronomy, the formation of our globe and the structure of the universe, to the manufacture of a needle or a nail—who could discuss, in the same conversation, and with equal accuracy, if not with the same consummate skill, the most forbidding details of art and the elegancies of classical literature, the most abstruse branches of science and the niceties of verbal criticism.

"There was one quality in Mr. Watt which most honorably distinguished him from too many inventors, and was worthy of all imitation—he was not only entirely free from jealousy, but he exercised a careful and scrupulous self-denial, and was anxious not to appear, even by accident, as appropriating to himself that which he thought belonged to others. . . . . The

only jealousy I have known him to betray was with respect to others, in the nice adjustment he was fond of giving to the claims of inventors. Justly prizing scientific discovery above all other possessions, he deemed the title to it so sacred, that you might hear him arguing by the hour to settle disputed rights; and if you ever perceived his temper ruffled, it was when one man's invention was claimed by or given to another; or when a clumsy adulation pressed upon himself that which he knew to be not his own."

Immediately after the death of Mr. Watt, an affectionate, but, by universal testimony, a just tribute was paid to his memory by Mr. Jeffrey in an eloquent description of his character. "Independently of his great attainments in mechanics," he says, "Mr. Watt was an extraordinary, and in many respects a wonderful man. Perhaps no individual in his age possessed so much and such varied and exact information—had read so much, or remembered what he had read so accurately and well. He had infinite quickness of apprehension, a prodigious memory, and a certain rectifying and methodizing power of understanding which extracted something precious out of all that was presented to it. His stores of miscellaneous knowledge were immense, and yet less astonishing than the command he had at all times over them. It seemed as if every subject that was casually started in conversation with him, had been that which he had been last occupied in studying and exhausting: such was the copiousness, the precision, and the admirable clearness of the infor-

mation which he poured out upon it without effort or hesitation. Nor was this promptitude and compass of knowledge confined in any degree to the studies connected with his ordinary pursuits. That he should have been minutely and extensively skilled in chemistry and the arts, and in most of the branches of physical science, might perhaps have been conjectured; but it could not have been inferred from his usual occupations, and probably is not generally known, that he was curiously learned in many branches of antiquity, metaphysics, medicine, and etymology; and perfectly at home in all the details of architecture, music, and law. He was well acquainted, too, with most of the modern languages, and familiar with their most recent literature. Nor was it at all extraordinary to hear the great mechanician and engineer detailing and expounding for hours together the metaphysical theories of the German logicians, or criticising the measures or the matter of the German poetry.

"It is needless to say that, with these vast resources, his conversation was at all times rich and instructive in no ordinary degree; but it was, if possible, still more pleasing than wise, and had all the charms of familiarity with all the substantial treasures of knowledge. No man could be more social in his spirit, less assuming or fastidious in his manners, or more kind and indulgent toward all who approached him. He rather liked to talk, at least in his latter years; but though he took a considerable share of the conversation, he rarely suggested the topics on which it was to

turn, but readily and quietly took up whatever was presented by those around him, and astonished the idle and barren propounders of an ordinary theme by the treasures which he drew from the mine they had unconsciously opened. He generally seemed, indeed, to have no choice nor predilection for one subject of discourse rather than another; but allowed his mind, like a great cyclopædia, to be opened at any letter his associates might choose to turn up, and only endeavored to select from his inexhaustible stores what might be best adapted to the taste of his present hearers. As to their capacity, he gave himself no trouble; and indeed such was his singular talent for making all things plain, clear, and intelligible, that scarcely any one could be aware of such a deficiency in his presence. His talk, too, though overflowing with information, had no resemblance to lecturing or solemn discoursing, but, on the contrary, was full of colloquial spirit and pleasantry. He had a certain quiet and grave humor, which ran through most of his conversation; and a vein of temperate jocularity, which gave infinite zest and effect to the condensed and inexhaustible information which formed its main staple and characteristic. There was a little air of affected testiness, and a tone of pretended rebuke and contradiction, with which he used to address his younger friends, that was always felt by them as an endearing mark of kindness and familiarity, and prized, accordingly, far beyond all the solemn compliments that ever proceeded from the lips of authority. His voice was deep and powerful, though he commonly spoke

in a low and somewhat monotonous tone, which harmonized admirably with the weight and brevity of his observations, and set off to the greatest advantage the pleasant anecdotes which he delivered with the same grave brow, and the same calm smile playing soberly on his lips. There was nothing of effort, indeed, or impatience, any more than of pride or levity, in his demeanor; and there was a finer expression of reposing strength and mild self-possession in his manner, than we ever recollect to have met with in any other person. He had in his character the utmost abhorrence for all sorts of forwardness, parade, and pretension; and, indeed, never failed to put all such impostures out of countenance by the manly plainness and honest intrepidity of his language and deportment.

"In his temper and dispositions, he was not only kind and affectionate, but generous and considerate of the feelings of all around him, and gave the most liberal assistance and encouragement to all young persons who showed any indications of talent, or applied to him for patronage or advice. His health, which was delicate from his youth upwards, seemed to become firmer as he advanced in years; and he preserved, up almost to the last moment of his existence, not only the full command of his extraordinary intellect, but all the alacrity of spirit and the social gayety which had illumined his happiest days. His friends in this part of the country never saw him more full of intellectual vigor and colloquial animation—never more delightful or more instructive—than

in his last visit to Scotland, in autumn, 1817. Indeed, it was after that time that he applied himself, with all the ardor of early life, to the invention of a machine for mechanically copying all sorts of sculpture and statuary; and distributed among his friends some of its earliest performances as the productions of a young artist, just entering on his eighty-third year.

"This happy and useful life came, at last, to a gentle close. He had suffered some inconvenience through the summer; but was not seriously indisposed till within a few weeks of his death. He then became perfectly aware of the event which was approaching; and, with his usual tranquillity and benevolence of nature, seemed only anxious to point out to the friends around him the many sources of consolation which were afforded by the circumstances under which it was about to take place. He expressed his sincere gratitude to Providence for the length of days with which he had been blessed, and his exemption from most of the infirmities of age; as well as for the calm and cheerful evening of life that he had been permitted to enjoy, after the honorable labors of the day had been concluded. And thus, full of years and honors, in all calmness and tranquillity, he yielded up his soul without pang or struggle, and passed from the bosom of his family to the presence of his God."*

* This is a beautiful sketch of Mr. Watt's character, but it will be noticed with regret that no clear reference has been made to the truths of the gospel in enumerating the sources from which Mr. Watt drew his tran-

Such was James Watt. His history, although that of a private individual, whose career was unmarked by any striking adventure, is one full of interest, and rich in lessons of improvement. It points out in an emphatic manner the triumphs of perseverance, and the mode in which difficulties, however complicated, yield to patient application and well-directed ability. To artisans, the life of James Watt is especially profitable, for it shows how one of their own class achieved the highest social distinction, not by listening to the arts of the demagogue, but by the honest exercise of the talents God had intrusted to him.

If ever human fame were a desirable thing, that acquired by Watt might be coveted. By perfecting an ingenious invention, he enlarged the resources of his country, and multiplied the powers of industry over the whole world. He has made the force of his genius felt in the mine and in the factory: he has given new wings to commerce, and revolutionized our modes of conveyance both by land and sea. He has introduced, in short, an agency, the power of which is experienced in every country in the globe, and one, too, whose tendency, when not perverted by the selfishness of man, is to abridge toil and to multiply the comforts of social life. If ever earthly fame were to be coveted, such a fame as

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quillity in the prospect of death. No life, however amiable, however useful, can serve as the ground of a sinner's acceptance before God. Other foundation can no man lay in this respect than that which is laid in God's word, Jesus Christ and Him crucified.

this might be envied. But we would not be dealing fairly with our readers, were we not to state that all fame which has reference only to this state of existence, and which is not connected with the possession of God's favor, is a poor and a fleeting thing. It perishes with the life that now is: it cannot benefit its possessor in the life that is to come. How far James Watt was the subject of those renewing influences of the Holy Spirit—without which, according to the declarations of Scripture, no man can enter the kingdom of heaven—we know not, and are not called upon to decide. While awarding him, then, a full measure of applause—while hailing him as a benefactor of his species—we would remind our readers that all here is temporary and evanescent, and that even triumphs such as Watt achieved, have, when viewed in the light of eternity, but a subordinate importance. The one thing needful is to be born again by the Holy Spirit: to have a true repentance for sin: to believe in the Lord Jesus Christ to the saving of the soul; and to evidence our faith by a holy and a godly life.

Without these blessings we are poor, whatever else we may possess. With them we are rich, "take what Thou wilt away."

CHAPTER VII.

THE RAILWAY AND LOCOMOTIVE-ENGINE.

THE application of the steam-engine to railway travelling was an event of momentous importance to the social and commercial interests of mankind. The increased facility of intercourse between distant places has already produced a change upon the surface of society, and many modifications in its habits and institutions will probably follow. Railway history, therefore, is not only interesting, as exhibiting the development of a mechanical contrivance and commercial enterprise, but as a new phase in the ever-changing conditions of mankind. In comparison with this history, meagre as it is in event, the records of ancient martial exploits, the ingenious disputes of philosophical scholarship, and even the triumphs of classical poetry and eloquence, lose much of their boasted interest and importance.

To obtain a connected history of the inventions which ultimately led to the establishment of the present system of railway travelling by locomotive-engine, it is necessary to distinguish between the adoption of the rail, and the invention and application of the engine. The railroad is not,

as many imagine, a modern contrivance. For many years it has been employed as a cheap and safe mode of conveyance for heavily laden wagons. It was long after the railroad had become common in the vicinity of pits, quarries, and mines, that the locomotive steam-engine was placed upon it as a motive-power. But when the union had been established between the rail and the steam-engine, time only was required to extend the system, which had been advantageously employed for heavy loads with slow velocities, to the transit of passengers, with a speed only limited by the precautions demanded for safety.

It would be useless to inquire when the railroad was first introduced, or by whom it was constructed. These are questions to which no answer can be given, but would open the way to endless theories and discussions. But we do know that it has been employed for the last two hundred years for the conveyance of coal from the Newcastle collieries to the brigs on the Tyne. Roger North, the brother of Lord-keeper Guildford, says, that in his time straight and parallel rails of timber were laid from the pits to the river for the transit of coal, "whereby the carriage is so easy that one horse will draw four or five chaldrons of coal, which is an immense benefit to the coal merchant."

In all places where the transit was constant and the loads very great, wood was soon found to be an improper material for the construction of rails. To prevent the loss of power from friction, and to avoid the expense of restitution, iron

was proposed, and in 1738 experiments were made upon cast-iron rails at Whitehaven, but they were not at that time adopted. In 1760, the wood rails at the Colebrook Dale iron-works were covered with iron plates, and great advantage was derived from this alteration, the friction and the wear being considerably diminished. In 1799, William Jessop, a celebrated engineer, laid down an iron edge-rail at Loughborough; and in 1810, William Outram fixed a cast-iron flanged rail at Little Eaton, in Derbyshire—a form of rail called after him the Outram, or, in abbreviation, the tram-rail. Iron rails of various forms were thus introduced, but many of the old wood rails remained in existence long after the advantage of iron had been satisfactorily proved; and, among others, that at Prior Park quarries, near Bath, which was fixed in 1741, and had from that time been employed for the transit of building-stone. In 1811, one hundred and fifty miles of railway were at work in South Wales, and the same mode of transit had been generally adopted in situations where it could be usefully employed, as in Newcastle, Sunderland, Derby, and other coal and iron districts. But here it must be remarked, that at this time the system of railway conveyance had been no further developed than was necessary for the transit of heavily laden wagons down inclined planes. The first step had been taken, but much, altogether independent of the introduction of the locomotive-engine, remained to be done before the railroad could be made generally useful.

The idea of employing rails for passenger traffic originated with Dr. James Anderson. This gentleman was the editor of an annual periodical work, called "Recreations in Agriculture," and, in the volume published in 1800, he recommended the use of rails to farmers, and suggested the adoption of general lines throughout the kingdom, to be laid down by the side of turnpike roads. By way of trial, he proposed the construction of one from London to Bath. The same scheme was recommended two years after by Mr. Edgworth, in a paper inserted in Nicholson's Journal. The advantage he offered for the adoption of his proposal was, that stage-coaches and gentlemen's carriages would travel at the rate of eight miles an hour. These schemes were premature, and had they been adopted could have led to no practical benefit; but the mention of them tends to show the direction in which thought was at that time moving: they were indications that society was rising to a state which could not long be satisfied without an improved mode and greater facility of communication.

The celebrated Duke of Bridgwater one day remarked, after he had successfully introduced his system of water-carriage by canals: "We shall do well enough if we can only keep clear of those tram-roads." There were, perhaps, few men beside himself who at that time had the smallest anticipation that the railroad would ever become the successful rival of that noble enterprise in which he was so conspicuously engaged, and least of all James Brindley, his engineer,

who, with more self-congratulation than was becoming, boasted that "rivers were made to feed canals." When these remarks escaped these two great men, there was little reason to think that the rails, at that time used only in coal-mines, would, in less than half a century, spread themselves through the length and breadth of the land, and that over them would be carried almost the entire traffic of the country.

Having briefly noticed the introduction and improvement of the rail, and its extension in certain mining districts, we may now proceed to relate the first attempt made to work upon it a locomotive-engine. This was a task of no ordinary difficulty. An engine, with a condensing apparatus, such as had been invented by Mr. Watt, with a large supply of water, was evidently unsuited for locomotion. The space required for such an engine, and the weight of the water necessary for condensing the steam, at once excluded it from any application to railway travelling, except as a stationary engine, and even to that object it would in the present day be thought inapplicable. The abandonment of the condensing apparatus compelled the use of what is called high-pressure steam, or, in other words, steam with an elastic force greater than that of atmospheric air. This fact disposes of an injudicious attempt made by some of Mr. Watt's friends to secure him the honor of inventing or proposing the present system of railway travelling. The mere mention of the possibility of applying the steam-engine to locomotive pur-

poses, gives no claim to the honor of actually effecting that object. We should not, perhaps, much err in stating that the work was unsuited to his genius; but however that may have been, his engine was inapplicable to railway purposes, and through life he had been the consistent opponent of that principle by which alone the object could be attained.

High-pressure engines, or those which work against the pressure of the atmosphere, instead of in a vacuum, were invented before James Watt was born. Leupold's engine, proposed about 1720, was constructed upon this principle. From the date of Mr. Watt's invention of the double-action engine to the expiration of his patent, the non-condensing engine was almost entirely neglected, but since that period it has been the principal object of study among engineers, and in mines and factories has superseded the condensing apparatus. Messrs. Trevethick and Vivian were the first to introduce, but not without much opposition, the high-pressure engine. This was done in 1802, and their engines soon came into use in many manufactories, where they were found to work steadily and without accident, frequently under a pressure of steam equal to from fifty to seventy pounds on the square inch, a force four or five times as great as that of the atmosphere. Still, there was an impression upon the public mind that much danger was incurred in the use of steam with such an expansive force, and many provisions, some of which are now abandoned, were consequently made to pre-

vent the occurrence of anticipated accidents. To avoid the possibility of too high a pressure of steam from the carelessness or ignorant daring of the engine-driver, the boiler was furnished with two valves, only one of which was under his control; the other, being self-acting, was loaded as might be deemed necessary by the manufacturer. But the danger most to be apprehended was liable to arise from a rapid evaporation of the water, and an inadequate supply to make up the waste. If the evaporation were greater than the supply, there would be a continually decreasing quantity of water in the boiler, until at last all the water would be expended, and the space entirely filled with steam. Such a condition would be productive of danger from two causes. The heat received by the iron, of which the vessel was formed, being retained instead of communicated, would soon raise the temperature of the metal to a red heat, and the boiler would be burned in the same way as an empty culinary vessel when placed upon the fire. But, in addition to this, if cold water were at such a time admitted, the steam would be condensed, and a vacuum be formed, in consequence of which the external pressure of the atmosphere would be unresisted, and the destruction of the boiler by collapse would in all probability follow. To prevent the occurrence of such accidents, a metallic plug was soldered into the boiler, at that height below which it was desirable the level of the water should not fall, so that if on any occasion the evaporation should be greater than the supply, it might be arrested

before any danger could accrue; for as soon as the water had fallen below the plug, the heat of the fire would melt the solder, the plug would fall out, and the steam escape.

The high-pressure engine, introduced by Mr. Trevethick into the manufactory, suggested to him the means of constructing a locomotive, and that which he had invented for one purpose became his model for another. In 1804, he constructed the first locomotive steam-engine, and in the following year it was working experimentally upon the tram-road of the Merthyr Tydvil colliery, in South Wales. It is curious to contrast the construction of this engine, with what it was able to perform, with the engines of our own day, and what they are daily doing. The cylinder was eight inches in diameter, and the stroke was four feet nine inches. If it stood by one of the compact Herculean engines on the North Western or Great Western lines, one might smile at its strange cog and fly-wheels, but the difference of speed would be more marked than the construction. The first locomotive engine performed its trial journey of nine miles at the rate of five miles an hour, without taking in water, dragging carriages containing ten tons of iron. Though it is a customary thing for an engine to travel, with a load of one hundred and fifty tons, at a speed of from fifteen to thirty miles an hour, this first effort of the new-born athleta must not excite our ridicule. We know not whether the opinion be strictly correct, but to us this trial seems the most wonderful effort that was ever made by man

in connection with the steam-engine. The planting of the steam-engine upon a railway was the great mechanical labor of the age, and to Mr. Trevethick the honor of its accomplishment is indisputably due; and this may be justly said without in the slightest degree detracting from the merit of George Stephenson, to whom he virtually assigned the charge of his noble invention. A comparison between the merits of these two mechanists is well drawn by a modern writer: "Stephenson cannot be looked upon as having, in the character of an inventor, gone much beyond Trevethick; rather, we should say, he did not do as much, for it was a greater thing to build the first locomotive and set it going, than to make a better one than that which worked at Wylam: it was greater to make the first locomotive with one cylinder, than to build a new one and put in two cylinders. Trevethick, however, left the locomotive to get on as it could—it was the steady care of George Stephenson which fostered it."

In the introduction and establishment of a new discovery or mechanical contrivance, men generally find enough to do in meeting and overcoming the difficulties which attend its practical application. But it is a singular fact, that, at the commencement of the railway system, engineers gave themselves an incalculable amount of unnecessary labor about a fictitious difficulty, and made provisions to correct an evil which was afterwards found to have no existence. It was thought that the adhesion between the tires of the wheels and the surface of the rail would be too small to admit

of the propulsion of a steam-carriage up inclines and over plain surfaces; and that the power of the engine would be expended in turning the wheels without obtaining any forward motion, or if by chance some speed were obtained, that it would be lost in slipping and sliding. Strange enough, no one thought of trying the amount of adhesion between the wheels and the road, which would have settled the question at once; but, assuming a supposition as a fact, many skilful engineers began to study by what mechanical contrivance the imaginary difficulty might be overcome. So thoroughly convinced were they that the friction was insufficient, and that an engine could never travel up an incline without assistance, that they were even in haste to secure a legal protection for their inventions. Mr. Blinkensop, of Middleton Colliery, took out a patent in 1811 for the application of a cog-wheel, worked by the engine, to run in a rack-rail laid by the side and parallel with the road, by which contrivance he proposed to prevent slipping and give a progressive motion. This invention was adopted at Middleton Colliery, and continued in use till the year 1830. In 1812, Messrs. Chapman, giving up all hope of self-propulsion, took out a patent for the use and application of a chain down the centre of the road, attached to a wheel under the carriage, and turned by a connection with the engine. A proposal was made in the following year, by another inventor, to attach to the engine a mechanical contrivance similar in motion to the fore feet of a horse. Unhappily for

these ingenious devices and their authors, as well as all others who had spent their time and money in providing for an imaginary difficulty, it was discovered, by an experiment which ought to have been tried long before, that there was sufficient friction between the wheels and the rail to give effective propulsion to the engine; not only when by itself, but also when dragging heavy loads. This experiment was tried under the most unfavorable circumstances, and in all states of weather, and the results put the vexed question entirely to rest, and turned the attention of mechanical engineers to less speculative and more useful projects.

In the year 1813, Mr. George Stephenson received an order to construct a locomotive-engine for the Killingworth Colliery; and this is the first time we find his name in connection with the railway history of England. In a speech delivered after an entertainment given to him at Newcastle, he said: "The first locomotive I made was at Killingworth Colliery, and with Lord Ravensworth's money—yes, Lord Ravensworth and Company were the first parties who would entrust me with money to make a locomotive-engine. That engine was made thirty-two years ago, and we called it My Lord. I said then to my friends, that there was no limit to the speed of such an engine, provided the works could be made to stand. In this respect great perfection has been reached, and in consequence a very high velocity has been attained." The successful working of this engine demonstrated beyond all

dispute the applicability of the locomotive-engine to the railroad, but it was still confined to the mines and the colliery; no one seems to have thought of its introduction as a competitor with the ordinary modes of travelling. The interval, however, which passed between the construction of Stephenson's first locomotive, and the formation of the first railway for general purposes, was not lost. A new study had been opened to the mechanist, and both the engine and the rail were capable of great improvement, and for both numerous patents were taken.

But time rolled on, and the day came when the railroad was to be brought from the dusky fields of the coal-mine, where it had been seen only by engineers, workmen, and geologists, to be exhibited on the high road of commerce to the curious gaze and inspection of all men. It was resolved to construct a line of rail between Darlington and Stockton; but those who projected and supported this enterprise little knew to what mighty ends that small beginning was to lead. It was opened in 1825, but the locomotive was not there: it was worked by horses, and with this insufficient motive-power a speed of ten miles an hour was immediately obtained.

The successful results of the Darlington and Stockton Railway led to the proposal of a line between Liverpool and Manchester, and in 1826 the company formed for that purpose received an act of incorporation. The principal object entertained by the directors at this time was the transport of heavy goods at moderate speeds. It is no

disparagement to their judgment or foresight to state, that no one was more surprised by the results of their enterprise than they themselves were. When the work was commenced, it was not even decided by what motive-power the traffic should be carried on, and when the conflict of opinion had somewhat subsided, it was still undetermined whether stationary or locomotive engines should be adopted. Nor were their doubts likely to be removed by the eagerness of the public to assist their deliberations. "Multifarious were the schemes proposed to the directors," says Mr. Booth, their treasurer, "for facilitating locomotion. Communications were received from all classes of persons, each recommending an improved power, or an improved carriage: from professors of philosophy down to the humblest mechanic, all were zealous in their proffered assistance. England, America, and continental Europe, were alike tributary. Every element, and almost every substance, was brought into requisition, and made subservient to the great work. Every scheme which the restless ingenuity of man could devise was liberally offered to the company—the difficulty was to choose."

As the road approached completion, the directors, still undecided between the locomotive and stationary engine, appointed engineers to visit the railways where practical information could be obtained, and to report to them the relative merits of the two systems. Although these authorities could not agree in their verdict, the result of the inquiry was in every respect favorable to the

adoption of the locomotive system. It was not only proved to be less costly in construction, and to require a less annual outlay in working, but to possess many advantages not to be obtained by fixed engines, and to avoid many evils fairly to be anticipated from them. The argument, however, which probably had most weight upon the minds of the directors was, that in the event of an accident upon the line, a suspension of traffic must be the result if stationary engines were used.

A more momentous commercial question was perhaps never proposed to any body of men than that which waited the decision of the directors of the Liverpool and Manchester Railway, when they were consulting upon the merits of the stationary and locomotive engines for railway traffic. Time has proved that their decision was correct.

As soon as the directors had resolved upon the adoption of locomotive engines, they took into consideration by what means they were to secure the most effective construction of them for the traffic of their road. No plan seemed to them so fair to inventors and manufacturers, or so likely to effect their own object, as a public competition; and, to offer an inducement for trial, it was resolved that a reward of five hundred pounds should be given to the maker whose engine, so constructed as to fulfil certain conditions thought necessary for successfully working the railway, should have the greatest speed. The low standard of sufficiency adopted by the directors is a proof

that the capabilities of the engine were quite unknown. The conditions required were, that there should be no smoke: that the pressure of the steam should not exceed fifty pounds on the square inch; and that the engine should be supported on springs, be not more than fifteen feet in height, and draw three times its own weight at the rate of ten miles an hour. The proposals were published in the spring of 1829, and the trial was made in the autumn of that year.

On the day appointed, three engines entered the lists—the Rocket, made by Stephenson; the Sanspareil, by Hackworthy; and the Novelty, by Braithwaite and Ericson. The place of trial was a level piece of rail, a mile and a half in length, near Rainhill, over which the engines were to travel ten times backward and forward between stations erected at each end of the novel course, making a journey of thirty miles. The Sanspareil had only passed eight times between the stations when it was disabled. The distance it travelled was twenty-two and a half miles, which it performed in one hour, thirty-seven minutes, and sixteen seconds: its greatest velocity was twenty-three miles an hour. The Novelty can scarcely be said to have made an experiment, for it had only twice passed the stations when the joints of the boiler gave way. The Rocket performed the whole of the journey twice: the first time in two hours, fourteen minutes, eight seconds: the second time in two hours, six minutes, forty-nine seconds. Its speed during the trips is said to have varied from twenty-nine to eleven and a

half miles an hour. The trial, as it turned out, was rather an estimate of good workmanship than of the principle of the engines, for had the Sanspareil completed the journey in a time proportioned to that in which it ran twenty-two miles and a half, its speed would have been greater than that of the Rocket in its first trip. The prize, however, was justly awarded to Mr. Stephenson, as his engine complied with all the conditions of the competition. The directors had good reason to be satisfied with the result, having stipulated for ten miles an hour and gained fifteen, though the failure of two engines out of three may have given them some anxiety.

The opening of the Manchester and Liverpool Railway may be considered as the commencement of the railway system: it was like the little stream, which startles us on the uplands with its turbulence and noise, but when followed in its course is found to spread itself over the country in a broad and majestic stream. It was on this occasion, it will be remembered, that Mr. Huskisson met with the accident which in a few hours terminated his life—an event which gave occasion for a second trial of the speed of the locomotive. Falling from weakness and timidity at the approach of a train, with his leg upon the rail, the engine and carriages passed over, and broke both the tibia and the thigh, frightfully crushing the bones and lacerating the flesh. By his own request he was removed to Eccles, a distance of fifteen miles, in twenty-five minutes: so that on this, the first day of travelling by loco-

motive-engine, a speed of thirty-six miles an hour was attained. Notwithstanding all the delay necessarily attending so fearful an accident, the unfortunate gentleman was removed from the spot where it occurred to the house of his friend within an hour. The termination of the catastrophe is still in the recollection of many of our readers. At noon the accident happened, and nine hours afterwards Mr. Huskisson died.

It would be obviously unsuited to the character of this volume to attempt a description and comparison of the three engines which competed for speed upon the Liverpool and Manchester Railway, but it will not be useless to draw the attention of the reader to the fact that the celerity of the Rocket was chiefly due to the great surface of water exposed to the action of the fire. The boiler was six feet in length, of a cylindrical form, and with flat ends, at one of which was the chimney, and at the other the fire-box. Through the lower part of the boiler twenty-four tubes were passed longitudinally, three inches in diameter, communicating at one end with the fire-box, and at the other with the chimney. These tubes formed passages for heated air, and being entirely surrounded with water, much additional heat was communicated, and the formation of vapor proportionally increased. One hundred and eighteen feet of heated surface was thus obtained, and, as the only limit to speed in locomotive-engines is the power to produce steam, a great advantage was evidently secured. The number of the tubes in locomotives has been increased from time to

time, and in a boiler recently exhibited by the Great Western Railway Company, there were no less than three hundred and five. These tubes were formerly made of copper, but brass has been substituted, as that amalgam has been found to last from six to eight times longer than the first-mentioned metal.

To prove the necessity of a large supply of steam for the locomotive-engine, and, consequently, the need of increasing the evaporating surface, it is only requisite to trace the action of the engine upon the carriage. We are frequently told by persons who have just left a railway, that they have had a pleasant ride, and travelled at the rate of thirty miles an hour, as if it were information so much a matter of course, that the only wonder would have been if the train had not arrived at the appointed time. We confess, however, that nothing yet done by machinery so much surprises us as the speed attained by the locomotive-engine, and the reader will share our astonishment if he will observe the action of the engine in the performance of a journey of thirty miles in one hour. Such a speed is at the rate of about forty-five feet in a second. Suppose the wheels to have a diameter of five feet, they must make three revolutions per second to pass over the stipulated distances in the time. To produce one revolution of the wheels, the piston of the engine must move once up and down the cylinder, and for three revolutions this motion must be repeated three times, for which the cylinder must be six times filled with steam. Hence, to travel thirty miles an

hour, the cylinder must through the entire journey be filled and emptied of steam six times a second. Nor is this all that can be done by a locomotive-engine. There are daily trains, upon every line, which travel, without injury to the machinery of the engine and its connections, at a much greater speed. Many persons have travelled at double the velocity, or sixty miles an hour, and the piston of the engine has then moved six times up and down a cylinder twelve times filled and discharged in a second. Mr. Stephenson had good reason to say that there was no limit to the speed of such an engine, provided the works could be made to stand.

No better examples of what the locomotive-engine is, as now worked upon English railways, can be found than two noble structures which were on view in the Great Exhibition of 1851 in Hyde Park—one intended for a narrow, the other for a broad guage line. Their dimensions and powers, as given in the Exhibition Catalogue, are instructive, as illustrative of modern manufacture, but still more so when compared with the earlier specimens of locomotive-engines.

One of these engines was constructed by Messrs. Bury and Company for the London and North-Western Railway. It is supported on four pair of wheels, and has the driving wheels placed under the fire-box. This engine has 2285 feet of heating surface. The diameter of the cylinder is 18 inches, the length of stroke 24 inches: the diameter of driving wheels 8 feet. The weight of the engine empty is 32 tons: the necessary

supply of coke and water for working it is equal to 4 tons more. The evaporation, when at full work, is equal to 1140 horse-power: the pressure of steam 120 pounds on the square inch. The boiler is very low, and the greatest height is on the extreme wheels, which insures steadiness.

With this engine may be compared that made by the Great Western Railway Company, in their works at Swindon. It is one of the ordinary class of engines, employed, since 1847, for passenger traffic. According to the description given of it in the Exhibition Catalogue, it is capable of taking a passenger train of one hundred and twenty tons, at an average speed of sixty miles an hour upon easy gradients. The evaporation of the boiler, when in full work, is equal to 1000 horse-power, of 33,000 pounds per horse—the effective power, as measured by a dynamometer, is equal to 743 horse-power. The weight of the engine empty is 32 tons; coke and water 4 tons. The empty tender weighs 9 tons; 1000 gallons of water 7 tons 3 cwt.; of coke, 1½ ton—giving a total weight for the loaded tender of 17 tons 13 cwt. The heated surfaces are:—Fire-box, 156 feet, 305 tubes, 1759 feet. Diameter of cylinder, 18 inches, length of stroke, 24 inches; diameter of driving wheel, 8 feet; maximum pressure of steam, 120 pounds. The actual consumption of coke, with an average load of 90 tons, and an average speed of 29 miles per hour, including stoppages, would average 208 pounds per mile.

This brief account of the locomotive-engine would be incomplete without some allusion to the

attempts which have been made to introduce it upon the common road, especially as the engine itself had its origin in a desire to make a steam-carriage to traverse what were then the highways of England. When Trevethick commenced the construction of a locomotive-engine, it was intended to run upon the rough turnpike road; and although he abandoned his first project, and by placing it on a rail established the railway system of the kingdom, the idea was retained by many inventors, and successive attempts were made to carry into operation his design. The success attending many of these speculations proves that the design was not so absurd as some persons, without sufficient reason, were at the time willing to believe, and anxious to enforce. The difficulty of placing the locomotive upon the high road is not so much in the design and arrangement of the machinery as in the economy of work. The annual cost of a locomotive must always be much greater on a common road, however smooth it may be, than on a rail; partly because there is a greater resistance, but chiefly because there is a greater liability to derangement, and the necessary cost of repairs is immensely increased.

Mr. Goldsworthy Gurney was one of the first and most enterprising of those inventors who attempted to construct a steam-carriage for the road. This gentleman was a scientific chemist, and his name is well known in association with the oxy-hydrogen microscope, and as the successor of Dr. Thompson to the professorship of chemistry at the Surrey Institution. In the construction of

the engine, and still more of the boiler, Mr. Gurney exhibited admirable ingenuity, and by opponents as well as friends it was allowed that his trials were successful. Before an experiment was made, it was thought the resistance between the wheels and the road would not be sufficient for the propulsion of the carriage up a steep hill, but this he practically disproved by driving the engine on several occasions up Highgate Hill, and afterwards by a journey from London to Bath. The success of the experiments, however, increased the opposition, and one objection after another was raised, but chiefly, it must be confessed, by persons who, however honestly expressing their opinions, were interested in the failure of the invention. The possibility of a boiler explosion was perhaps the only objection indulged in by the public. The quibbles of highway commissioners, and the abuse of stable-boys, were merely a repetition, in a new form, of the objections before made to the railway system. But none of these impediments would have prevented the ultimate introduction of the locomotive upon the turnpike road, had not experiment proved that the cost of working it would have been greater than upon railways, and that competition in the present state of science was useless.

The rapid extension of the railway system, and the comparative safety in travelling it has produced, are little less wonderful than the improvements which have been made in the locomotive-engine. There are now in the United Kingdom about six thousand five hundred miles of railway

in constant work, and in the United States there are ten thousand miles in operation, and nine thousand in progress. Supposing the latter to be complete, which they will be at no distant period, the British and American railways, united as a continuous line, would encompass the earth at the equator.

CHAPTER VIII.

THE STEAMBOAT AND MARINE ENGINE.

When steam was first studied in modern times as a mechanical force, it was with the intention of applying it to the propulsion of vessels. The invention of Blasco de Garay, the Spanish sea-captain, it will be remembered, was to give motion to a vessel, and, although nothing is known of his machinery, paddle-wheels were employed. This idea (whether it was original, or borrowed from some preceding but unknown inventor, we cannot tell) was never lost sight of by any subsequent mechanist. Nor is this strange; for although new discoveries are frequent in other branches of science, practical mechanics consist in the application of known, and frequently the most common agents, to new and beneficial purposes.

Papin, whom we have also mentioned as a steam-engine projector, proposed to apply his design so as to move vessels against wind and tide. The mode in which he designed to accomplish this bears a close resemblance to the arrangement now adopted in steamboats. His contrivance was to place a shaft across the vessel, and at each end to fix a paddle-wheel, motion being given to

the shaft by connection with the engines. Savery, another steam-engine projector, already mentioned, says that his contrivance might be very useful in ships, but that he must leave the application to those who are better acquainted with maritime affairs: strangely enough, however, he took out a patent for a shaft and paddle-wheels, for the propulsion of vessels, which he worked by a capstan. This engine, as he calls it, he tried on the Thames, but its usefulness, as he himself informs us, was denied by Mr. Dummer, the surveyor of the navy, because it was the same sort of contrivance that had been used at Chatham, in the year 1682, for towing government vessels, and had been employed at a loss to the crown. This, as Dr. Muirhead states, was probably the vessel made under the direction of Prince Rupert, having paddle-wheels worked by horses; "and which, on a trial on the Thames, witnessed by Papin, beat the king's barge, manned by sixteen rowers."

These facts—and many others might be added if necessary—prove that three hundred years ago, at least, a shaft and paddle-wheels were fixed in a vessel to propel it against wind and tide. The want of a sufficiently powerful and constant force made this design useless: as the railroad waited for the locomotive, so did the shaft and paddle-wheels for the marine engine. We shall, therefore, do little injustice to our subject by passing over all the vain efforts to propel vessels without sails and oars by "new inventions and devices,"

and proceed at once to the examination of the history of the marine engine.

As soon as Mr. Watt had constructed his single-action steam-engine, the Americans suggested its application to the purposes of navigation, and, as early as the year 1783, an attempt was made by Fitch and Rumsey to propel a vessel by steam. They failed, it is true, but more from the want of suitability in the engine to the purpose for which it was employed, than from deficiency of mechanical skill and perseverance. But their unsuccessful attempt was no discouragement to others: the design may have been for a time suspended, but was not abandoned. In 1791, John Stevens, of Hoboken, commenced the study of the steam-engine and its application to navigation, and to his great honor continued his experiments for a period of sixteen years, occasionally assisted and advised by Livingstone, Roosevelt, and the elder Brunel. After this long and tedious course of investigation, conducted with ingenuity and perseverance, he was not, as he hoped to be, the first to establish a steamboat on an American river. Fulton was a few weeks before him, and during that period obtained from Congress the exclusive right to navigate the Hudson with a steam-vessel—a monopoly which ought not to have been granted, and was afterwards properly withdrawn, as being unconstitutional.

The fact that Fulton was the first to navigate an American river with a steam-vessel, is sufficient to draw our attention to the history of his

proceedings, and the means by which he gained his honorable distinction. But, besides this, the question of precedence between Great Britain and America is to be decided, if it be worth the discussion, by his career. Fulton, it appears, had, like many others, been studying the steam-engine, with the intention of making it useful in navigating vessels. The investigations and experiments in which he had engaged, led him to certain opinions as to the mode in which his object was to be gained. To procure further information, or to obtain assistance for his enterprise, he visited England, and in 1802 proceeded to Scotland. There happened to be at that time a small steam-vessel on the Forth and Clyde Canal, which had been built as an experiment for Lord Dundas, and was occasionally employed for towing. This little boat, it appears from indisputable authority, was propelled by a horizontal engine, and so well answered the expectation of its inventor, that the directors of the canal refused to allow the vessel to ply on their waters, because it produced undulations on the surface which were injurious to the banks. Fulton, as was most natural and proper, was anxious to see the "Charlotte Dundas," and at his request several trips were made, that he might have an opportunity of examining the action of her machinery. Now, how much information Fulton obtained from this examination —whether he gained all his practical knowledge in the little engine-room of this model steamboat—or whether the design was far inferior to what he had in contemplation, no one can decide,

nor is it necessary for the settlement of a question of priority. The "Charlotte Dundas" was floating on the waters of the Forth and Clyde Canal, and for her size was an effective and well-working boat: she must, therefore, be considered as the first steam-vessel, until it is shown that some other vessel was afloat and at work before her. But although thus much must be allowed to Great Britain as her share in the first introduction of steam navigation, it takes nothing from the honor of Fulton or of America, to whom belongs the undivided credit of having regularly established the system of water locomotion, which upon a Scotch canal had been proved possible.

From England Fulton proceeded to France, hoping, it appears, to have interested Napoleon in his design, and to have received his assistance in the establishment of his great object—a steam navigation. From no government could he have had so good a reason to anticipate success, for it was seldom that Bonaparte neglected any proposition which could by possibility turn to the honor and advantage of France or the discomfiture of England. Whether the Consul failed to perceive the advantage he would have gained in all his warlike designs by the possession of steamboats, or whether he doubted the possibility of constructing them, we may in either case recognize the providential hand of God in the neglect with which he treated Fulton and his inventions. The possession of a steam navy would doubtless have armed Napoleon with a weapon that would greatly have aggravated his contest with England,

however much the final issue of that contest might have remained the same. The time has now happily arrived when, in amity and mutual confidence, the two nations can join in the encouragement of scientific and mechanical invention, for the improvement of commerce and the establishment of peace; though we are sorry to add, for warlike enterprises too.

Fulton was disappointed of the assistance he had hoped to receive from Bonaparte, but his loss was more than recompensed by the coöperation and advice of Livingstone, who was at that time in Paris as the representative of America to the consular government of France. It was scarcely possible that two such men, both enthusiastic for the same object, should meet without arranging some plan to forward the enterprise in which they had severally spent much time and money. Livingstone at once perceived that his countryman possessed great mechanical invention and skill, and he was sufficiently acquainted with the subject to judge of the practicability of his views. Satisfied on these points, he entered with great earnestness, but with judicious caution, into the scheme, resolved to give America the benefits he fully anticipated from the discovery. Satisfied with some experiments first made at Plombières, and afterwards on the Seine, near Paris, Livingstone engaged to provide money for the building of a vessel, and Fulton returned to the United States to superintend its construction. To prevent failure from an imperfect or badly manufactured engine, it was thought desirable to obtain

it and the steam apparatus from England. Drawings were according made, and sent to Bolton and Watt for execution. Every thing was now in preparation for the grand experiment, but many difficulties were yet to be overcome, and many sources of delay arose independently of the disadvantage of receiving the engine from England. In 1807, however, Fulton launched his steam-vessel into the Hudson, and in the beginning of 1808 she was working regularly between New York and Albany, with a speed of about four miles an hour, which was afterwards raised to six miles an hour by the adoption of improvements.

The greatest speed obtained in any of Fulton's boats was nine miles an hour, and this he considered all that could be used with advantage. This was a low estimate of the effective power of steam navigation, and may prove that he had a far less accurate notion of what could be done with the marine engine than Stephenson had of the speed of the locomotive. But we cannot examine the form of the engine adopted by the American engineer, and the application of its machinery, without admiring his genius and forethought. The arrangements of the engine-house in modern steamers are in many respects essentially the same as those adopted by Fulton. The paddle-shaft was carried across the vessel, and the wheels were urged on, in the same manner as at the present time; and although he introduced but one cylinder, which is still the condition of many of our river boats, he applied a beam on

each side, and the connecting rods were attached to a crank.

When Stevens found himself excluded from the navigation of the Hudson by Fulton's monopoly, he selected the Delaware as a suitable station for working his vessel, and in so doing secured to himself the honor of making the first sea voyage in a vessel propelled by steam. But as soon as the traffic of the Hudson was thrown open, the younger Stevens determined to become a candidate for its commerce, and a most formidable competitor he was to his rival. Fulton had been accustomed to perform the voyage from New York to Albany, a distance of about one hundred and forty-five miles, in fifteen or sixteen hours. Stevens's boats were faster, and completed the voyage in twelve hours—a saving of time so important, that, to secure it, passengers, in many other countries besides America, would be willing to suffer some inconvenience, if necessary. Under these circumstances, Fulton could not indulge the hope of maintaining his position, or long continuing a successful competition: he was convinced that the traffic was lost, and wisely resolved either to make the voyage by night, when time was less important, or to employ his vessels as steam-tugs. At this early period in the history of steam navigation, many of the boats upon the Hudson performed their voyages at the rate of ten miles and a half per hour, a circumstance which may diminish our surprise that the same passage is now constantly made at more than double that speed.

It is not difficult to find a reason for the early

attention of our citizens to steam navigation; nor do their perseverance and success give any cause for surprise. Although our country was in an infant state, its population consisted of emigrants from Europe, who carried over the Atlantic the intellectual strength and civilized habits of their native lands, adding to those sources of power the enterprising spirit which generally distinguishes an emigrant people. If we view the physical conditions and peculiarities of our country, in connection with the circumstance that but a small portion of it was populated, the reason why a rapid water communication was considered so necessary is evident. Our coast line, from the Gulf of St. Lawrence to the mouth of the Mississippi, is not less than four thousand miles in extent, almost everywhere presenting safe natural harbors. The rivers flowing through the continent are of great length and depth, and are navigable to vessels of a large class for hundreds, and in some instances thousands of miles. The lakes, or inland fresh-water seas, the largest in the world, were attracting to their shores parties of emigrants, who, for the purposes of commerce and mutual support, needed a line of communication not yet opened through the luxuriant forests. The same wants were everywhere felt: the same hope everywhere expressed, ambition and patriotism were excited; and no labor was too onerous, no enterprise too daring, while a prospect of success remained.

Fulton's success in our country soon recalled the attention of the Scotch engineers to the ap-

plication of the steam-engine to navigation. Although Symington, who designed and constructed the "Charlotte Dundas," had failed in maintaining her upon the Forth and Clyde Canal, the objection of the directors, which destroyed his hopes, could not apply to a vessel on the river. Henry Bell, of Glasgow, was the first who determined to make the experiment, and test the truth of this conclusion. In 1811, he ordered John Wood, afterwards well-known as a shipbuilder, to build him a small vessel of twenty-five tons' burthen. This vessel, forty feet long, and ten feet in the beam, was accordingly constructed at Port Glasgow, and fitted with an engine of four horse-power. In January, 1812, the "Comet," for that was the name given to her, began to ply for goods and passengers between Glasgow and Helensburgh, Mr. Bell's native place, performing her voyages with considerable regularity at a speed of about five miles an hour.

In 1814, Mr. Cook, of Glasgow, built a steam-vessel, called the "Glasgow," and fitted her with an engine of sixteen horse-power. Great care was taken in the construction of the engine for this boat, and many improvements were introduced. It was looked upon at the time as a test of this new mode of propelling a vessel in the water. Her success was perfect; and in the following year the same gentleman built another steam-vessel, which was taken from Glasgow to Dublin, and then round Land's End to London, to demonstrate the possibility of a sea voyage. She was afterwards placed on the London and

Margate station, and was the first steamboat upon the river Thames.

In 1816, Maudsley and Field, who have since been so extensively engaged in the manufacture of marine engines, introduced a pair of fourteen horse-power each into a new vessel; but the use of two engines did not originate with them, for in 1814 Bolton and Watt had fixed two in a boat called the "Clyde." At this period, many improvements had been made, and some of the most important had their origin in the Soho works. Bolton and Watt, who were not to be left behind in this new application of the noble contrivance which had established the reputation of their works, were active in their efforts to produce suitable and efficient engines, and in 1817 purchased the "Caledonia," and, having fitted her with a pair of fourteen horse-power combined engines, took her to the Scheldt, where many experiments were made, important data determined, and new adaptations approved and introduced.

Next in the history of steam navigation comes the name of that ingenious and enterprising man, David Napier. By his order, Denny, of Dumbarton, built the "Rob Roy," which he supplied with an engine of thirty horse-power. In 1818, she began to run between Greenock and Belfast, but in the following year was stationed between Dover and Calais. Thus he acquired the honor of not only establishing a steam communication between Great Britain and Ireland, but also between an English and French port, crossing first the Irish and afterwards St. George's Channel.

In 1820, he built the "Talbot," a fine vessel, with two engines of thirty horse-power each, and she took the station between Dublin and Holyhead. The London and Leith passage was opened in 1821, and the "James Watt" and the "Soho," a hundred and twenty horse-power each, established this important line of communication.

Up to this time, nothing had been done by the Admiralty: many objections, on the contrary, had been raised to the use of steam in the navy. The elder Rennie, however, succeeded in obtaining an order to tow the "Hastings," a seventy-four gun line-of-battle ship, from Woolwich to Chatham, and it was hoped that the success of the experiment would induce the Admiralty to adopt some mode of providing the country with steam vessels. The "Eclipse," a Margate boat of sixty horse-power, was employed, but she was inadequate to the task: the experiment failed, and the "Hastings" sailed into the Medway. The failure, however, was not of serious importance, for Mr. Oliver Lang, the master-builder of Woolwich Dockyard, received an order to proceed with the construction of a steam vessel for which he had prepared the necessary plans. This vessel, called the "Comet," was a hundred and fifteen feet long and twenty-one feet in the beam, with a draught of nine feet, and was fitted with a pair of forty horse-power engines.

The General Steam Navigation Company was established by William Joliffe in 1825. The "George the Fourth," and the "Duke of York," vessels of between five and six hundred tons

burthen, and with engines of a hundred and thirty horse-power, were built, and, in September, 1827, commenced their voyages, one between London and Cadiz, the other between London and St. Petersburgh. Both the ships answered the expectations of their owners, but the company upon consideration thought it desirable to restrict their trade to the British Channel and German Ocean; and, having resolved to sell these vessels, offered them to the government, by whom they were purchased. About the same time the "Enterprise," which made a voyage to Calcutta, touching at the Cape of Good Hope, was built, a vessel of five hundred tons burthen, with two one hundred and twenty horse-power engines, to which Maudsley and Field's brine pumps were attached. Thus, in a period of thirteen years, by unassisted private enterprise, and the talent of British engineers and ship-builders, the steamboat had been brought to comparative perfection, and was running not only between almost all the principal mercantile ports of Great Britain and Ireland, but was also visiting at regular intervals many of the continental harbors, and even venturing to cross the oceans which separate Europe from Asia and Africa.

We have now seen the steam vessel fairly launched upon the ocean, pursuing her course, through calm and storm, from continent to continent, crossing the equator and venturing on the Northern Ocean. Before we trace further the establishment of that great maritime communication which the steam vessel has now opened be-

tween all the civilized nations of the earth, we must pause for a moment to consider one of the great impediments presented at the outset of the vast enterprise, and the means by which it has been overcome.

When the application of the steam-engine to sea-going vessels was first proposed, a difficulty was anticipated which experiment confirmed, but scientific inventions have removed. The use of sea-water in the boiler was expected to be a serious inconvenience, and not unattended with danger. Sea-water contains in solution a large quantity of common salt, (muriate of soda,) and in less proportions sulphate of soda and the muriates of lime and magnesia. The deposition of these salts within the boiler, it was well known, would be the necessary result of the evaporation of the water, and the sediment could not be avoided, without some mode of discharging the water before it was saturated. Suppose, by way of illustration, the boiler to be filled with sea-water, and steam to be raised: then watch the effect that would be produced in the course of a few hours. Evaporation commences, and the water is rapidly discharged in the form of steam. But the salt is not evaporated: that substance remains and accumulates, so that at every interval the water in the boiler is more salt than it was before. But the time comes when the water is saturated, and can hold no more in solution. Deposition then follows, and in a few days the bottom of the boiler is covered with a cake of salt.

But while the evaporation produces a sediment

of salt exceedingly injurious, a still more dangerous effect is produced by the incrustation of the boiler-plates by the other mineral substances. These salts are indifferent conductors of heat, and the effect of placing an almost non-conducting substance between the boiler-plates and the water is so much to be dreaded, that we need not stop to inquire what other evils arise from the presence of these compounds. When they have formed a crust upon the inner surface of the boiler, the heat cannot be freely transmitted to the water, and in consequence the iron plates of the boiler are raised to a higher temperature than the liquid they enclose. The plates are consequently softened, and as the temperature is rarely uniform over the entire surface of the boiler, there is an irregular expansion, and the joints are opened, or flaws are made in weak and defective parts.

To prevent such an accumulation of saline matter as would saturate the water and cause deposition, it was and is still, in many vessels, the custom to discharge a portion of the water frequently from the boiler, by a process called "blowing off." Suppose a cock fixed near the bottom of the boiler in connection with a tube which at the other end enters the sea. When this cock is turned, the pressure of the steam in the boiler upon the surface of the boiling water is sufficient to drive out the whole of the liquid. This is the effect in that process called "blowing off:" it is the forcing out of the boiler into the ocean a portion of the water before it has become so saline

as to cause deposition by saturation. But as there must be on every occasion a great loss of heat and ineffective consumption of fuel by removing a large quantity of boiling water and supplying its place with cold, the process should be repeated as seldom as possible. To lessen the quantity of sea-water received into the boiler, it is fed from the condenser, so that the sea-water is only used to make up the loss during evaporation, and a much more pure liquid is thus supplied.

It would have been strange if, in this age of research and invention, a process of so much importance had been left to the option of a steam-vessel engineer, without some better guide than a written order from a board of directors, "to blow off every two or three hours." Some invention was required by which an engineer could ascertain the precise strength of the saline solution in the boiler, and direct the operation, not at stated periods, but when the condition of the water made it necessary. Such an invention was proposed by Messrs. Seaward, and is worthy of explanation. To understand the operation of this contrivance, it must be known that one thirty-second part of the weight of sea-water is due to the presence of salt, and that when the salt increases to the proportion of nine parts in thirty-two, deposition commences. Messrs. Seaward provided a gauge with two balls of unequal weight, but both sufficiently heavy to sink in sea-water. The lightest of these would float when the saline matter in the boiler was in the proportion of five parts to thirty-two of water, and the heavier when it

exceeded six parts: with such a guide as this, a deposition in the boiler could only happen from the carelessness or indifference of the engineer, and the loss of power was reduced as low as possible by confining the operation of "blowing off" to the periods when it was necessary.

This device, however, required to be connected with some mode of measuring the quantity of brine withdrawn from the boiler: it informed the engineer of the impurity of the water, but left him to decide what quantity should be removed. To avoid the waste of heat, and consequently of fuel, resulting from the discharge of more hot water than necessary, Messrs. Seaward fixed a tank containing exactly one ton of water to receive it. The precise quantity blown off was thus always determined, and at the same time accidents were prevented from the carelessness of the men in leaving the blow-off cock open.

Messrs. Maudsley and Field invented another mode of preventing the accumulation of brine in marine boilers. This contrivance is called a brine pump, and was successfully introduced into the Enterprise, as already mentioned, and afterwards into the Great Western and other first-class steamers. The idea the inventors endeavored to carry out in their mechanical arrangement was, that so much brine might be removed from the boiler as should be in such proportion to the water supplied to it, that the saltness or density of the water in the boiler should never be greater than that of the sea. To explain the mode in which this is done, let us first suppose it necessary to pump out

the brine when the weight of salt, compared with that of sea-water, is in the proportion of five parts to thirty-two; and in the next place, let it be admitted that four-fifths of the water received by the boiler is evaporated, or converted into steam. It then follows that if five cubic feet of water be delivered into the boiler for every one cubic foot of brine discharged, the same density or saltness will be always preserved. Brine-pumps, constructed with a view to the maintenance of this proportion between waste and supply, and worked by the engine, lift the water from the lower part of the boiler, and discharge it into the sea. The feed-pumps, on the other hand, also in connection with the engine, are at the same time providing for both the waste by evaporation and the discharge from the brine-pumps. To make this contrivance complete, it was only necessary to prevent the waste of heat occasioned by pumping one-fifth of the hot water into the sea. This is in a great measure accomplished by sending the hot brine through a tube enclosed in the one which conducts the feed water. An important conservation of heat is thus attained, for the temperature of the brine is so reduced that it does not exceed 100° when permitted to escape into the ocean.

Having explained the means by which the most important objection to the navigation of the ocean by steam-vessels was overcome, we may turn to a consideration of that last great effort of science and commerce, which fully demonstrated the universal applicability of steam to the purposes of

navigation. The success which in all instances had attended the efforts to establish steam communication between distant ports, led to the inquiry whether it would be possible to connect England and the United States in the same manner. This was a subject of deep thought and anxiety to the mercantile world. The honor of making the trial, and that a successful one, is due to some gentlemen resident at Bristol. For this great experiment, Paterson, a ship-builder at Bristol, was ordered to construct a vessel, and to Maudsley and Field were entrusted the manufacture of the engines. In March, 1838, the "Great Western" was ready for sea; and as this was the first steam-vessel crossing the Atlantic, and afterwards established to connect the old and new worlds, the reader may have some curiosity to know her dimensions and the power of her engines, though such details are generally barren of interest to unprofessional readers. Her length was 210 feet, breadth of beam 38 feet, draught 15 feet, tonnage 1240. Her engines were 210 horse-power each: cylinders 73 inches diameter: stroke 7 feet, and 15 strokes per minute. The voyage was expected to occupy twelve days, and she was supplied with 500 tons of coal. The total weight of the engines, boilers, water, and paddle-wheels, was 420 tons. On the 8th of March she sailed from Bristol, under the command of Captain Hosken, with seven passengers and a cargo of fifty tons, and reached New York, a distance of 3000 miles, on the 23d of the same month, making the voyage in thirteen days ten

hours. On the 7th of May, she left New York on her voyage home, with seventy passengers, and entered the port of Bristol on the 23d, making the passage in fifteen days.

The success of this experiment established confidence, and the speed and regularity with which the Great Western continued to perform her voyages removed the fears of the most timid. The "British Queen," the "Liverpool," and the "President" were successively built; and although the loss of the last-named vessel* damped for a time the ardor of the capitalist, the traffic has been fully established, and the voyage is made with so little risk, and with so much certainty as to time, that there is almost more regularity in crossing the Atlantic than sailing the same distance over any other part of the ocean.

Steam navigation has been much benefited by the introduction of iron as a material of construction instead of timber. The proposal was thought strange enough when it was first announced—some laughed, others shook their heads in doubt and amazement. A sad catalogue of impossibilities were prepared, and the project generally condemned. But, in spite of hindrances, the experiment was made, and proved successful. Iron steamers are not above half the weight of those constructed of wood, the tonnage being the

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* That excellent man, the Rev. G. G. Cookman, formerly chaplain to Congress—an eloquent and devoted advocate of missions—was lost in the President. He was a noble Christian, and an ardent friend.—[The Editor.

same. This enables them to carry a heavier cargo, or in the event of that not being required, they take a less draught of water, and do not present the same resistance to the propelling power. The comparison is clearly made by Lardner:—"The nature of their material renders them more stiff and unyielding than timber; and they do not suffer that effect called hogging, which arises from a slight alteration that takes place in the figure of a timber vessel in rolling, accompanied by an alternate opening and closing of the seams. Iron vessels have the further advantage of being more proof against fracture upon rocks. If a timber vessel strike, a plank is broken, and a chasm opened in her many times greater than the point of the rock which produces the concussion. If an iron vessel strike, she will either merely receive a dinge, or be pierced by a hole equal in size to the point of the rock which she encounters." Some examples of the strength of iron vessels were given by Mr. Macgregor Laird, in his evidence before the Committee of the House of Commons on steam navigation, among which the following may be mentioned:—"An iron vessel, called the 'Alburkah,' in one of their experimental trials, got aground, and lay upon her anchor: in a wooden vessel the anchor would probably have pierced her bottom; in this case, however, the bottom was only dinged. An iron vessel, built for the Irish Inland Navigation Company, was being towed across Lough Derg in a gale of wind, when the towing-line broke, and she was driven upon rocks, on which she

bumped for a considerable time without any injury. A wooden vessel in this case would have gone to pieces. A further advantage of iron vessels (which in warm climates is deserving of consideration) is their greater coolness and perfect freedom from vermin."

The Great Britain was a remarkable vessel: a brief account of her construction and engines will not be inappropriate in this place. The following are the principal dimensions of her hull:—Length of keel, 289 feet; length aloft, 322 feet; main breadth, 50 feet 6 inches; depth of hold, 32 feet 6 inches. The weight of iron used in the construction of the hull was about 1040 tons, and of wood, 370 tons. The weight of the engines and boilers, exclusive of water, was 520 tons. The total weight of the hull, engines, and boilers, was 1930 tons; and it is hardly possible to imagine such a mass to be floating on water, directed by the helm, and driven forward by the force of steam, till we calculate the weight of water she displaced, and call to recollection that every body must float whose weight is less than that of the water it displaces.

The Great Britain was constructed with bulk-heads—an admirable contrivance for the separation of the hull into compartments by water-tight partitions. In this vessel there were five: three of which were carried to the upper deck. These bulk-heads are important, not only as ties to strengthen a vessel, but serve the same purpose as bladders to a bad swimmer, and prevent her from sinking should she spring a leak. Supposing

such an accident to occur, only one compartment would be filled with water, and this would not be sufficient to sink her, for she would still be lighter than the water she displaced. Bulk-heads may thus, in many instances, save cargo, crew, and passengers, when they are introduced into a vessel, whether propelled by sails or steam.

When the Great Britain was designed, it was the intention of her engineers to fit her with paddle-wheels; but while she was building, a small steamer called the "Archimedes" came into Bristol. This vessel belonged to the company who had purchased Mr. Smith's invention for the Archimedean screw, and was propelled by that contrivance, to exhibit the value of the invention, and to promote its adoption. The engineers of the Great Britain availed themselves of the opportunity thus offered of testing the value of this means of propulsion, and, after full inquiry and many experiments, resolved to adopt it in preference to the paddle-wheel. The screw of the Great Britain, according to the description of one of her engineers, was made of wrought-iron, and was fifteen and a half feet in diameter, and the pitch of one revolution was twenty-five feet. Its weight was 77 hundred-weight. Upon the second trial of the Great Britain in the Bristol Channel, she had a speed of twelve and one-eighth knots an hour, and on another occasion, when she ran down the Bristol Channel to Ilfracombe, she had an average speed of eleven and a maximum of twelve knots an hour. During her voyage from Bristol to London, she

experienced a heavy gale, but made the run, light-handed and under many disadvantages, at a speed of nine and a half knots an hour. The steam-engine employed to drive this screw had four cylinders, eighty-eight inches in diameter, with a stroke of six feet, and which were worked expansively: the steam, which had a pressure of four pounds on the boiler, was cut off at one-sixth of the stroke, or, in other words, when only one foot of the cylinder was filled with steam.

The progress of a steam-vessel and its speed must greatly depend upon the form and effectiveness of its paddle-wheels. It may, perhaps, be thought that they are almost past the range of mechanical improvement. Such an opinion is not tenable. The angle at which the paddles enter the water has much to do with their efficiency in propelling the vessel. The paddle-boards of the common wheel, which are fastened to the rim with nuts and stays, are so fixed that their planes, or flat surfaces, correspond with the radii, or lines drawn from the centre to points dividing the circumference into the necessary number of equal parts. When thus constructed, the entire force of the paddle-board is only obtained when it comes to the lowest point of the wheel: in every other position it is more or less ineffective, the greatest loss of power being when it enters the water. The efforts of engineering skill have been directed to the removal of this defect, and to provide a means by which the paddle-board shall enter and leave the water edgeway. The motion required is one similar to

that called feathering in rowing. The two most important methods were proposed for this purpose: that of Mr. Elijah Galloway, patented in 1829, and of Mr. Field, enrolled in 1833—the former is a mechanical contrivance for the motion of the paddle-board so as to regulate the angle of its immersion, and the other is a split paddle, constructed of several narrow slips, arranged one behind the other.

The steam-vessel has now been tried in all climates and in all weathers, and is found a suitable and safe means of transit in each. There is but one limit to her power—the quantity of coal she can carry. The necessity, therefore, of adopting every measure that can be devised for the conservation of fuel in sea-going vessels, is enforced by the fact that the duration of a voyage must be in proportion to the quantity of steam to be formed by the combustion of a given quantity of coal. Before the steam-vessel was steered seaward, the quantity of coal consumed was only a consideration of expense, and that was little regarded when a greater speed was to be obtained. But upon an ocean voyage, where the supply is limited, and a relay impossible, speed and the consumption of fuel must be estimated together. Great care is therefore required in the construction and setting of the boilers, the disposition of flues, and the arrangement of furnaces; but when every precaution has been taken, much will still depend upon the efficiency and care of the stokers under the direction of the engineer. A medium is required between a niggardly supply, with

which the full power of the engine cannot be obtained, and an excessive feed, producing an ineffective and useless combustion, more calculated to impede than hasten the evaporation of the water. In the early history of steam navigation, the importance of employing the radiated heat was not understood, but at the present time the most careful provisions are made, in both the locomotive and marine-engine, to obtain from it all the assistance it is able to give.

Our observations have hitherto chiefly referred to sea-going boats, but we must not close this chapter without a few remarks upon those employed in river navigation. All constructions must be judged by their suitability to the purposes for which they are designed. These are made for speed, and an excess of strength is more feared than the want of it. From this cause there is a great disproportion between the length of the vessel and its breadth of beam. The length of one now plying on the Hudson is three hundred and thirty-three feet, and its breadth only forty feet. The engine, for there is but one, is fixed on, and not under, the deck, and is connected by a crank with the axle of the paddle-wheels, which, in the vessel we have mentioned, are no less than thirty-nine feet in diameter. The engine has a cylinder six feet nine inches in diameter, with a twelve feet stroke repeated eighteen times a minute. These are dimensions which have no representatives in any of the engines seen in England; yet these long and narrow vessels, propelled by an engine of great weight and

power, have an average speed, upon the smooth waters of the Hudson, of twenty miles an hour, and many travel at the rate of twenty-three, between New-York and Albany, a distance of one hundred and forty-five miles, at the small fare of only half a dollar per passenger. These results may be called wonderful when compared with Fulton's first efforts on the same river, and even with Dr. Renwick's account of a voyage from New-York to Catskill, a distance of about ninety-six miles, performed, exclusive of stoppages, at a speed of fifteen and three-quarter miles an hour. This was but a few years ago. The speed, which was then almost incredible, is now half as much more.

A far different scene is presented on the Mississippi. The vessels plying on that river are built with their cabins and saloons six or eight feet above the deck, upon or under which the engine is fixed. In these vessels high-pressure engines are invariably used. Some years since, steam, with a pressure of one hundred and twenty pounds on the square inch, was commonly employed, and is now, in some instances, raised to two hundred pounds and upwards. Frightful accidents are, consequently, common upon the Mississippi.

The mention of the river steamboats calls to memory the comparison drawn by Jacob Abbot between the trial of its efficiency and the Christian's state of probation in this world. "When a large steamboat," he says, "is built with the intention of having her employed upon the waters

of a great river, she must be proved before put to service. The engineer resolves to try her, that her security and powers may be properly proved, before she is entrusted with her valuable cargo of human lives. He cautiously builds a fire under her boiler: he watches with eager interest the rising of the steam-gauge, and scrutinizes every part of the machinery as it gradually comes under the control of the tremendous power which he is cautiously applying. With what interest does he observe the first stroke of the ponderous piston! And when at length the fastenings of the boat are let go, and the motion is communicated to the wheels, and the mighty mass slowly moves away from the wharf, how deep and eager an interest does the engineer feel in all her movements, and in every indication he can discover of her future success! He examines most minutely and most attentively every part of her complicated machinery. He scrutinizes the action of every lever, and the friction of every joint. Here he oils a bearing, there he tightens a screw. One part of the machinery has too much play, and he confines it: another too much friction, and he loosens it. Now he stops the engine, now reverses her motion, and again sends the boat forward in her course. This is probation, trial for the sake of improvement. And what are its results? Why, after this course has been thoroughly and faithfully pursued, this floating palace receives upon her broad deck, and in her carpeted and curtained cabins, her four or five hundred passengers. They pour in one long

procession of happy groups over the bridge of planks: father and son, mother and children, young husband and wife, all with implicit confidence, trusting themselves and their dearest interests to her power. See her as she sails away—how beautiful, and yet how powerful are all her motions! That beam glides up and down gently and smoothly in its grooves, and yet, gentle as it seems, hundreds of horses could scarcely hold it still. There is no apparent violence, but every movement is of vast power. How graceful is her form, and yet how mighty is the momentum with which she presses on her way! Loaded with life, and herself the very symbol of life and power, she seems something ethereal, unreal, which, ere we look again, will have vanished away. And though she has within her bosom a furnace glowing with furious fires, and a reservoir of death, the elements of most dreadful ruin and conflagration, of destruction the most complete, and agony the most unutterable, and though her strength is equal to the united energy of two thousand men, she restrains it all. She was constructed by genius, and has been tried and improved by fidelity and skill; and one man governs and controls her, stops her and sets her in motion, turns her this way and that as easily and certainly as the child guides the gentle lamb. She walks over the hundred and sixty miles of her route without rest and without fatigue, and the passengers who have slept in safety in her berths, with destruction by water without and by fire within, defended only by a plank from the one, and by a

sheet of copper from the other, land at the appointed time in safety.

"My reader, you have within you susceptibilities and powers of which you have little present conception: energies which are hereafter to operate in producing fulness of enjoyment, or horror or suffering, of which you now but little conceive. You are now on trial. God wishes you to be prepared for safe and happy action. He intends that you shall be 'searched' and 'tried,' and the complicated movements of your heart examined, in order to detect what is wrong, to modify what needs change, and rectify every irregular motion. If our moral powers are to be tried upon the stream of active life, that what is right may be improved, and what is wrong remedied, renewed opportunities of moral practice are given you, that you may go on from strength to strength, until every part of that complicated moral machinery of which the human heart consists will work as it ought to work, and is prepared to accomplish the mighty purposes for which your powers are designed. You are on trial, on probation, now. You will enter upon active service in another world."

CHAPTER IX.

BOILERS AND THEIR FITTINGS.

Before we close this volume, we may make a few remarks on boilers and their fittings. Upon the form and arrangement of these the full efficiency of the many interesting and cleverly constructed engines we have mentioned depends. In fixing a steam-engine for work there is no detail to which the engineer directs his attention more closely than the form and setting of the boiler and the building of the furnace. The excellence of an engine is always judged by its power in relation to the cost of working, of which the consumption of fuel is an important and principal item. But that this estimate be correctly made, there must be not only a complete combustion of the coal or coke, but also an application of all the heat obtained to the formation of steam.

Before we proceed farther, it may not be unadvisable to review briefly the effects of combustion, and the modes by which heat is communicated. When a substance is burning, it is changing its chemical composition, or, in other words, it is undergoing the process of decomposition, which is usually attended by the evolution

of light and heat. Coal is a compound substance, consisting chiefly of the two elements, carbon and hydrogen. When carbon is raised to a temperature of about 700° it unites with pure oxygen, forming a gaseous compound called carbonic acid, during which a great heat is evolved, and the gas itself raised to an excessively high temperature. Oxygen and hydrogen also combine at a temperature of about 1000°, producing, by their chemical union, water; and this also is effected with a great disengagement of heat. But in the combustion of coal, hydrogen principally is evolved, in combination with carbon, in a gas called carburetted hydrogen, which is the gas employed in artificial illumination, and burns in the atmosphere with a bright yellowish red flame.

Heat is commonly said to be communicated in two ways, by conduction and radiation. When a bar of metal is heated at one end, its temperature is soon raised at the other: this is called an effect of conduction. If we stand before a fire we feel the heat: this is a communication by radiation. For conduction, contact is required: radiation is almost irrespective of space, for all the heat received in this world from the sun is thus transmitted. Properly speaking, there is no conduction, for no particles of matter are in absolute contact, but this is a subject we need not discuss here: the distinction will be useful to us, and we shall retain the terms as being sufficiently descriptive of the circumstances of communication without any refinement of reasoning.

When steam was first used as a motive-power,

the engineers were only careful for an arrangement by which the disengaged heat could be conducted through the boiler to the water it contained. The conservation of the radiated heat was entirely neglected. But just in proportion as the application of the steam-engine has been widened, and especially since its introduction to locomotive purposes on the ocean and railroad, the necessity of employing the radiated heat has been acknowledged. In the present day, not only is every precaution taken to employ it serviceably, but even the gases, which escape from the fuel at a very high temperature, are compelled to give up their sensible heat before they are allowed to escape into the atmosphere.

The forms of boilers are as various as the purposes to which engines are applied, and the situations under which they are fixed. If strength alone were considered, the spherical form would be the best for a boiler. Watt adopted that shape known as the wagon-head, which is semi-cylindrical at the top, flat at the sides and ends, and concave at the bottom. These flat surfaces are by no means calculated for strength, but as he seldom used steam with a pressure of more than five pounds on the square inch above the pressure of the atmosphere, they had a resistance quite equal to the duty required. It is a form still commonly adopted, though not generally approved.

The proportion of heating surface to the power of evaporation is a question of great importance in designing the form and settings of a boiler.

Mr. Watt estimated that from eight to ten feet of heating surface was sufficient for the evaporation of one cubic foot of water per hour. This proportion, however, is not now considered sufficient, though what it should be is undecided, for engineers adopt different data in their calculations. To secure this rate of evaporation, some consider twelve square feet of heating surface sufficient, while others estimate as much as eighteen.

But, in calculating the size of a boiler, the necessary quantity of water for evaporation must be considered, as well as the provision of a sufficient surface for that effect. It has been justly said that "the space within a boiler is appropriated to a twofold purpose: to contain the water to be evaporated, and a quantity of ready-made steam for the supply of the cylinder. If the space appropriated to the steam did not bear a considerable proportion to the magnitude of the cylinder, the momentary expansion of the steam passing to the cylinder from the boiler at each stroke would reduce the pressure of the steam in a great proportion, and unless the pressure in the boiler were considerably greater than that which the steam is intended to have in the cylinder, the pressure in the latter would be reduced below the proper amount. The proportion of the steam space in the boiler to the magnitude of the cylinder has been very variously estimated, nor can it be said that any practical rule of a general kind has been adopted. It is held by some that the steam space will be sufficient if it contain five

times the quantity of steam consumed at each stroke, while others maintain that it should contain at least ten times that quantity, and opinions vary between these limits."

The water-line to be maintained in a boiler must always be above the flues. If this be neglected, the heat of the flame or air, as the case may be, is not conducted from the boiler-plates. It is true the interior space is full of steam, but this is a slow recipient of heat, and while the increased temperature of the steam augments its expansive power, the accumulation of heat in the plates, or rather their increased temperature, lessens their power of resistance. If the water-line be above the flues, all the heat communicated to the plates is received by the water: so that, when raised to the boiling point, evaporation commences, and all the heat is employed latently in the formation of steam. There are, therefore, two evils resulting from an insufficiency of water in the boiler: the loss of heat and the destruction of the plates. Many contrivances have been suggested to indicate at all times the height of the water in the boiler, some of which, with the mode of supplying the waste from evaporation, will be presently mentioned.

To maintain the requisite level of the water in the boiler, it is necessary that the water received from the feed should be equal to that lost by evaporation. If the water admitted into the boiler be more than is necessary to supply the waste, the water-line will rise; if it be less, it will fall. But it is not customary to have a constant feed

for stationary engines—the water is admitted at intervals, the times when that is necessary being determined by the indications of the float. There is doubtless a great advantage in a constant feed proportioned to the evaporation, such as that invented by Mr. Field for marine boilers, but, in the adoption of such a contrivance, the attention of the engine-driver would be still necessary, as the amount of evaporation may be affected by local or accidental conditions. An intermittent feed, therefore, is, perhaps, all that can be obtained in a stationary engine with a load liable to sudden and great variations, so as to work with a due regard to economy. But as power is lost by the too great reduction of the temperature of the water, when the boiler is replenished at long intervals, an effort should be made to maintain the level with as little variation as possible, so as to prevent the necessity of pumping in a large quantity of water at a time. This is a duty requiring the constant attention of the engine-driver, and one which if neglected entails loss of power, and, it may be, dangerous consequences.

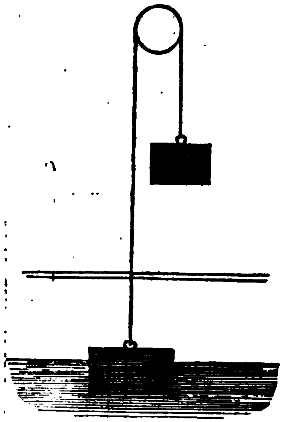
When Savery introduced his engine, he used two gauge-cocks for measuring the height of the water in the boiler. The arrangement was simple, and may be easily understood. Two pipes were introduced through apertures in the boiler, one descending a little below the proper water-line, while the other was fixed a little above it. Both pipes rose a few inches above the top of the boiler, and were furnished with stop-cocks. Supposing the water to be at its proper level, steam would

issue from one pipe when its cock was turned, and water from the other, the pressure of steam forcing the water up the tube immersed in it. Hence it followed that when both tubes discharged steam, the level of the water was too low, and when they both gave water, it was too high. This arrangement, though effectual enough if the engineer gave sufficient attention to it, was utterly useless if he were idle or forgetful. Something was to be done before the indication could be obtained, and there was nothing to suggest the necessity of attention. As soon as novelty and timidity ceased to have effect upon the mind, the feeling of confidence and security was produced. The stop-cocks were then seldom resorted to: a few minutes before the engine was started or stopped, they were perhaps examined, and for intermediate periods the engineer trusted to a common routine of duty, established by precedent and followed by habit, without taking the trouble to ascertain the real condition of the boiler, or the quantity of feed required.

To provide an indication appealing to the eye, without the trouble of an experiment, and thus removing in a great degree the validity of an excuse frequently made, of forgetfulness, many contrivances were suggested, and all were more or less successful. One plan was to fix a glass tube at the side of the boiler, one end entering it below the determined water level, and the other above. As the water in the tube must, under such circumstances, stand at the same level as the water in the boiler—the pressure of steam being

the same on both—the information received from this gauge is the same as if the boiler itself were made of glass.

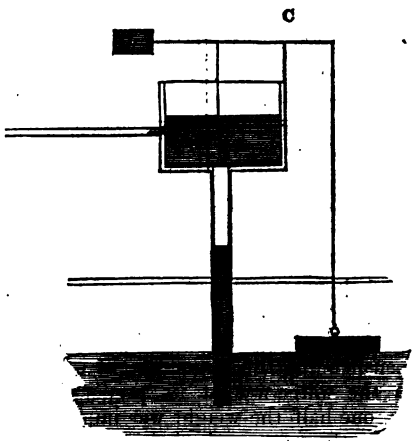
Another mode of obtaining the same knowledge was by a counterpoise. Two weights were



suspended over a pulley fixed on the boiler. The larger weight entered the boiler, and the smaller was suspended in the air. The length of the wire suspending the larger weight was such that when the water was at its proper level in the boiler, one-half the weight was immersed, and it then exactly counterpoised the lesser weight suspended in air. Everybody knows that bodies are lighter when weighed in water than they are in air. A bucket is easily drawn upward

so long as it is in water, but a sensible increase of weight is felt when it is drawn into the air. So the weight of the float increases as the level of the water falls, and decreases as it rises, and this change is of course indicated by the rise and fall of the counterpoising weight in air.

By a similar arrangement, a self-acting feed has been provided. The float and counterpoise are used in the same manner, but, instead of a pulley and chain, a lever is employed, moving upon C as its centre of gravity. To the

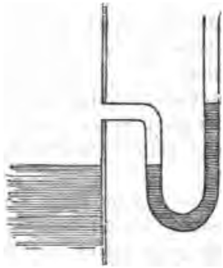


longer arm of the lever is attached a wire, connected with a valve opening into a tube communicating with the boiler. The cistern, at the

bottom of which the valve is fixed, is connected by the horizontal tube with the hot-water pump. As the water falls in the boiler, the float sinks with it, and that arm of the lever to which it is attached descends, producing an elevation of the other arm, which raises the valve and allows the water in the cistern to flow down the pipe into the boiler.

Many other inventions have been applied to boilers for the same object: to indicate the height of water, and to sustain the level by supplying a sufficient feed to restore the waste. It is, however unnecessary to multiply examples: the same or similar principles are adopted in all cases, and when the action of one or two is understood, the observer's ingenuity will enable him to discover the action of all others: to judge of the fitness of the application, and to estimate the relative merits of one design with another.

That there should be some method of determining the pressure of steam in a boiler needs no argument. An instrument made for this purpose is called a steam-gauge. Its action is similar to that of the barometer. Mercury is used for both, and as the metallic column in the one indicates the weight of the atmosphere, so the relative elevations of the other exhibit the pressure of steam. Supposing a curved tube to be used, as shown in the next diagram, the principle of the steam-gauge may be easily understood. Let it be at one extremity connected with and open to the boiler, and at the other exposed to the atmosphere. The necessary quantity of mercury being introduced,



the height to which it rises in either arm of the syphon-like tube will depend upon the relative pressure of the steam and the atmosphere. If the force of both be the same, the surfaces will be level: if the force of the steam be less than that of the atmosphere, the mercury will rise in that part of the tube in connection with the boiler; and if greater, in that open to the atmosphere. The height to which the mercury is forced in either tube above the level exhibits the pressure of the steam, one pound pressure on every square inch being calculated for every two inches of elevation. When glass cannot be used for the steam-gauge, which is often the case, a metal tube is employed, and a wooden float and rod is introduced into the atmospheric end: the elevation of the mercury is exhibited on a scale engraved upon the rod.

When steam of high pressure is required, as for locomotive-engines, the steam-gauge just described cannot be applied, on account of the

excessive length of tube that would be necessary. In such cases, a thermometer is used. How pressure is to be determined by an instrument intended to measure temperature may not be at once evident. It will, however, be remembered that steam has the temperature of the water from which it is produced, so that just as the boiling-point of the water is raised, the pressure to which it is exposed increases. There is, therefore, a relation between the temperature and pressure of steam. This has been accurately determined, and a double scale is attached to a thermometer: one to exhibit temperature, and the other pressure. Such is the steam-gauge employed in locomotive-engines.

There is one other provision to be made in the construction of a boiler: it must have a safety-valve, which is an arrangement for the escape of steam when it exceeds the pressure required. This valve is made of a conical shape, and is retained in its seat either by weights sliding on a rod or by a lever: in the former case the pressure is regulated by the addition or removal of weights; in the latter, by shifting the same weight upon the arm that supports it, nearer to or farther from the centre of motion. Two safety-valves are often and ought always to be provided. Where steam of high pressure can be generated, it is desirable that one should be out of the power of the engine-driver, so as to prevent him from increasing the elastic force beyond that which may be considered necessary or safe. If the second valve be not required for such a purpose, it is still useful,

as it is no unusual thing for these valves to be fixed, or, as it is technically expressed, locked in their seats. The frightful loss of life attending boiler explosions, which, though frequent, are few compared with the number of engines in constant work, should enforce the use of every provision suggested by science and demanded by experience.

Conclusion.

It has sometimes, by short-sighted prejudice, been objected to the steam-engine, that it has aggravated instead of alleviating human toil. Although, in some cases, this invention may have been perverted by avarice into an engine for selfishly amassing wealth at the expense of the comforts of others, yet it must be obvious, on the slightest reflection, that the steam-engine has not merely changed, but changed for the better, the condition of society—relieving multitudes from grinding toil, cheapening the cost of production, and giving enjoyments to the humbler classes which were previously confined to the upper and middle ranks of society.

Much, however, as we may admire the results of the steam-engine, and deservedly as we may honor the names of those who were associated with its discovery and improvement, we do not take a sufficiently enlarged view of the subject, if we omit to contemplate this invention in the light of a gift from God, graciously intended to alleviate that oppressive toil which is our heritage from our first parents' transgression. Moderate labor was a law of man's being, but that grinding

toil which, in every age, has been the lot of the great majority of the children of men, is the fruit and penalty of sin. It is the deadly principle of sin which has been the bane of man's social happiness: it has depraved his heart, burdened his conscience, poisoned his pleasures, and exposed him to the awful penalties of the wrath to come. In bidding farewell, therefore, to the reader who has accompanied us to the close of our subject, we would affectionately direct his attention to that gospel which is the only sovereign remedy for his temporal and spiritual maladies. To have a true repentance for sin: to be reconciled to God through faith in the blood of his dear Son: to have a saving interest in the Lord Jesus Christ: to be born again by the Holy Spirit; and to yield up the heart and life to be sanctified by his grace, and to be conformed to his will—these are blessings, real and substantial, which it is our highest interest to secure, and to lose which would be a calamity productive of unspeakable woe.

THE END.